BIOSTRATIGRAPHY AND BENTHIC FORAMINIFERAL MORPHOGROUPS OF THE MIOCENE MIXED CARBONATE AND SILICICLASTIC DAM FORMATION IN THE AL-LIDAM AREA, EASTERN PROVINCE OF SAUDI ARABIA

BY

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Dedication:
To my family

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In the name of Allah, the most compassionate, most gracious, and most merciful that have given me the ability, and capability to complete my studies at KFUPM.

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ABSTRACT

Full Name : [Septriandi Asmaidi Chan]
Thesis Title : [Biostratigraphy and Benthic Foraminiferal Morphogroups of the Miocene Mixed Carbonate and Siliciclastic Dam Formation in the Al-Lidam area, Eastern Province of Saudi Arabia.]
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The study of foraminifera from the Cenozoic formations especially in Eastern Saudi Arabia has not been fully documented compared to the Mesozoic carbonate and siliciclastic formations, which have been extensively investigated both in outcrop as well as in the subsurface due to their importance in the Arabian petroleum system. Regionally, few micropaleontological studies have examined the foraminiferal distribution in the Dam Formation, located in the Dammam Dome area, or the Dam Formation from southwestern Qatar. The Dam Formation exposed in the Al Lidam area however, has not been investigated for the distribution of foraminifera.

Four outcrops along the west to east direction from the Al Lidam escarpment were investigated in this study for paleoenvironmental reconstruction and to understand the vertical and lateral distribution of foraminiferal assemblages. The samples were processed using the standard acetic acid method, which extracts foraminifera from the lithified carbonate rock without destroying the fossil content. Disaggregation using acetic acid shows promising results, the foraminifera assemblage from the Dam Formation is dominated by calcareous porcellaneous Miliolina genera (*Quinqueloculina, Peneroplis, Triloculina*, *Cornuspira*, *Sigmoilinita*, *Coscinospira*, *Spirolina*, *Pyrgo*, *Borelis)*, followed

by hyaline forms (*Elphidium, Ammonia, Cibicides, Discorbinella*) and a minor percentage of agglutinated forms, e.g., Textularina.

The high percentage of calcareous porcellaneous taxa and the absence of planktonic foraminifera indicate that the Dam Formation was deposited in a restricted carbonate platform environment, very shallow hypersaline lagoon, gently sloping ramp (inner ramp) which ranges from supratidal to subtidal with local patch reefs towards the basin, and deposited in an arid subtropical environment with water temperature ranging between 20 and 35° C. Based on the observed assemblage composition, the present day Arabian Gulf can considered as modern analogue for the Miocene Dam Formation. The present day environment has not changed drastically since the Miocene

ملخص الرسالة

الاسم الكامل: سبتري أسميدي تشان

عنوان الرسالة: التراصف البيولوجي و المجموعات المورفولوجية للمنخريات القاعية للصخور الكربونية والصخور الرسوبية الأخرى في طبقة لدام المترسبة في العصر الأوسط من الدهر الحديث في منطقة جبل لدام في المنطقة الشرقية من المملكة العربية السعودية

التخصص: علوم أرض

تاريخ الدرجة العلمية: مايو 2016

هناك دراسات قليلة لطبقات الدهر الحديث في شرق المملكة العربية السعودية نظرا لتركيز معظم الدراسات على طبقات الدهر الوسيط الغنية بالنفط الخام. لذلك فإن هناك دراسات قليلة أيضا عن أحافير المنخريات في طبقة لدام الموجودة في قبة الدمام وجنوب غرب دولة قطر. هذه البحث سيقدم ولأول مرة دراسة عن المنخريات في طبقة لدام في منطقة جبل لدام التي لم يتم دراستها مسبقاً. هذه الدراسة ركزت على تحليل عينات عديدة من أربع مقاطع من طبقة لدام و تم استنتاج معلومات عن طبيعة البيئة التي ترسبت فيها هذه الطبقة إستنادا إلى إختلاف توزيع المنخريات فيها عموديا وأفقيا. تمت معالجة جميع العينات باستخدام حمض الأسيتيك بنجاح (حمض الخل المركز) وتم استخراج أعداد كبيرة من أحافير المنخريات من طبقة اللدام الكربونية وأهم هذه الأحافير هي جنس المخريات الخزفية Miliolina وتشمل المجموعة التالية (*Quinqueloculina, Peneroplis, Triloculina, Cornuspira, Sigmoilinita, Coscinospira, Spirolina, Pyrgo, Borelis*) وجنس المنخريات الزجاجية Hyaline وتشمل *Elphidium, Ammonia, Cibicides, Discorbinella*) بالإضافة إلى نسبة قليلة من جنس Aggultinated مثل Textularina.

بناءً على النسبة العالية من المنخريات الخزفية وعدم وجود أي عينات من المنخريات العالقة (Planktonic Foraminifera) تم استنتاج طبيعة البيئة التي ترسبت فيها طبقة اللدام وهي عبارة عن بيئة بحرية ضحلة عالية الملوحة ومعزولة عن مياه المحيط لكنها تتأثر بفعل تيارات المد والجزر مما يجعلها مساعدة لتكوين الصخور الكربونية. إضافة إلى ذلك, تمت ملاحظة تكتلات من الشعاب المرجانية في الأقسام الشرقية من طبقة لدام مما يدل على أن عمق مياه البحر كان يزداد باتجاه الشرق وأن حرارة المياه كانت بين 20 – 35 درجة مئوية ويمكن تصنيفها على أنها بيئة شبه استوائية.

بناءً على وجود مجموعة المنخريات التي تم استخراجها من طبقة لدام فإنه يمكن الاستنتاج أن بيئة الخليج العربي المعاصرة تشبه إلى حد كبير جدا بيئة العصر الأوسط من الدهر الحديث لطبقة لدام وأنه لم يحدث تغير كبير للبيئة البحرية لمنطقة شرق الجزيرة العربية منذ ذلك العصر.

CHAPTER 1

INTRODUCTION

As sedimentary particles, microfossils in particular benthic foraminifera, are normally used for biostratigraphical studies. Benthic Foraminifera are well-known indicators of the dynamics of sedimentation change and depositional environments based on their diversity and distribution patterns (Murray *et al*., 2006). Therefore, the presence of foraminiferal in a particular sedimentary package would provide important information that reflects sea level changes (transgressive–regressive), paleoenvironments, and also might aid in the distinguishing of sequences and sedimentary boundaries (Nagy *et al*., 2001).

The shallow marine successions of mixed carbonate and siliciclastics of the Miocene Dam Formation are very well exposed in the eastern part of Saudi Arabia, especially in the Al Lidam area which is considered as the type locality (Powers *et al*., 1966). In this area, rapid vertical and lateral changes of carbonate and siliciclastic rocks are observed within the Dam Formation. The significant changes within this formation are controlled by sea-level changes, sediment supply, climate, and tectonics during the time of deposition (Powers *et al*., 1966; Ziegler, 2001).

Foraminiferal morphogroup analysis is based on the overall shape of the foraminiferal test, and this approach is based on functional morphology as a direct response to the environment, and foraminiferal lifestyle and feeding strategies (Jones and Charnock, 1985). It is studied within the context of a semi-quantitative aspect of the assemblage study that is related to paleobathymetrical and paleoenvironmental changes through geologic time (Corliss, 1985; Jones and Charnock, 1985; Corliss and Chen, 1988; Murray *et al*., 2006) at the generic level for its application to interpret the depositional environment (Nagy, 1992).

1.1 Motivation

The study of foraminifera from Tertiary formations in the Eastern Saudi Arabia is not entirely established, and their taxonomy is relatively poorly known compared with the Mesozoic carbonate and siliciclastic formations (Hughes, 1997; 2000; 2005). The latter have been extensively investigated in outcrops as well as from cored subsurface samples due to their great economic and strategic significance, being the largest hydrocarbon-producing area in the world (Al-Husseini, 1997; Hughes, 2000; Cantrell *et al*. 2004). Recently, the Tertiary formations have become an important aspect of the Saudi Arabian petroleum system, as they produce hydrocarbons in offshore fields from the Hasbah, Hadrukh, and Dam Reservoirs (Hughes *et al*., 2012). In addition, many of the correlative formations with Dam Formation in other marginal locations of the Neo-Tethys, such as lower Fars Formation in SE Iraq and Kuwait are also known to be hydrocarbon reservoirs (Al-Juboury and McCann, 2008).

1.2 Problem Statement and Objectives

A number of investigations (e.g., Hewaidy, 1991, Tleel, 1973, Al-Enezi, 2006, and Al Saad and Ibrahim, 2002) have been conducted on the Miocene Dam Formation in Saudi Arabia and Qatar. Most of the studies are related to litho-stratigraphy, sedimentology, and sequence stratigraphy. Only a few micropaleontology studies have ever examined the foraminifera in the Dam Formation (Al Saad and Ibrahim, 2002; Al-Enezi, 2006) . However, there has not been any recent study conducted detail the distribution of foraminifera in the Al-Lidam area. Powers *et al*. (1966) remains the only study that reported the occurrence of foraminifera from the carbonates of the Dam Formation in the Jabal Al-Lidam area. The original study by Powers et al. was a preliminary survey for mapping purposes. These authors did not describe the foraminiferal species in detail, or report the distribution of foraminifera in the study area.

The detailed study of foraminifera therefore, needs to be conducted in order to have better understanding of the depositional history, depositional environment, and to assist in establishing three-dimensional depositional models of the Dam Formation in the study area.

Therefore, the main objectives of this thesis are summarized as follow:

1. Identification and documentation of the foraminiferal species and foraminiferal biofacies of the Dam Formation at its type locality.
2. Implementation and optimization of the Acedic Acid method for extracting microfossils from indurated Miocene carbonates
3. Analyses of foraminiferal assemblages using morphogroups with the objective of interpreting paleobathymetric and paleoenvironmental changes that prevailed at the time of deposition.
4. To understand the vertical and lateral distribution of the foraminiferal species and foraminiferal morphogroups in response to lithofacies and paleoenvironment, which is associated with sea-level changes (transgressive – regressive episodes), and depositional cycles.

5. Integration of foraminiferal biofacies data with the established sedimentology, and the stratigraphic study by Bashri (2015), and Ali (2016) to enhance and better constrain interpretations and understanding of the Dam Formation.

1.3 Study Area

The study area is located in the Al Lidam escarpment area of the Eastern Province of Saudi Arabia, located between 26°15'30" N to 49°28'30" E and 26°14'15" N to 49°31'30" E (Figure 1.1). The escarpment which is approximately 80 km west of Dhahran city, can be easily accessed via the Dammam-Riyadh highway. The outcrops examined in the current study are located south - southwest of lower and upper part type sections of the Dam Formation (Figure 1.1), which was previously reported by Powers *et al.* (1966). Mixed carbonate and siliciclastic facies of the Dam Formation are very well exposed in the study area, with outcrops strike direction trending mostly NNW-SSE (Figure 1.1).

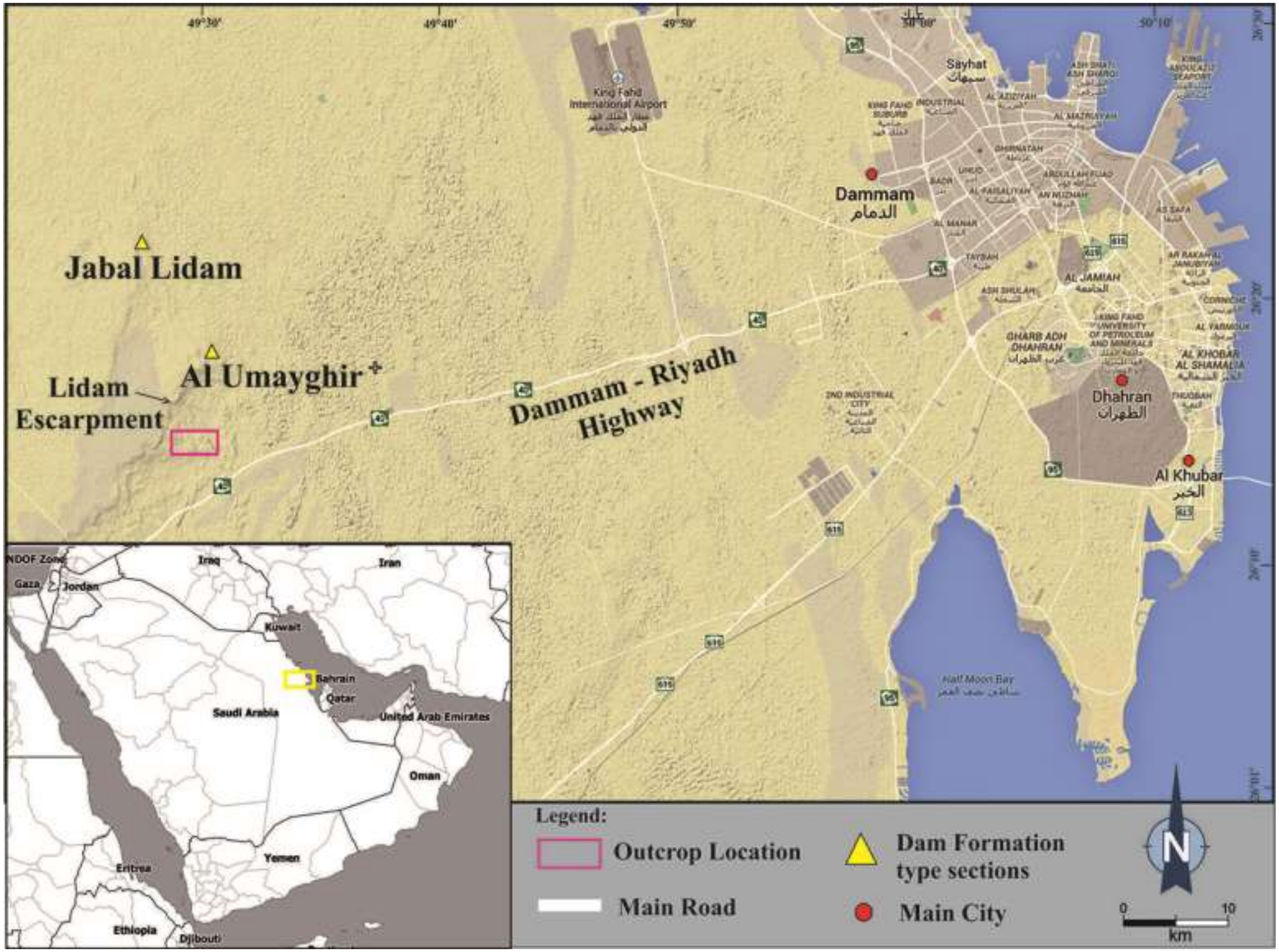


Figure 1.1. Aerial photograph from Google Earth showing the outcrop study location (red box)

1.4 Thesis Structure

This MSc thesis consists of six chapters: An introduction chapter (1) that explains the motivation, problem statement and study objectives. Literature review chapter (2), an overview about the study area including its geological background, tectonic evolution, and previous study on the Dam Formation. Chapter (3) deals with the methodology in this study, including sample collection, sample processing, describing the use of acetic acid method to extract microfossils from lithified carbonate rocks, and fossil identification. Chapter (4) deals with the results obtained in this study. Foraminiferal identification and documentation, morphotype analysis, and biofacies identification within the studied formation are included in this chapter. A discussion chapter (5) is devoted to discuss outcome that focus on the main objectives of this MSc thesis including the age of the Dam Formation, depositional environment, and distribution of the microfossils vertically and laterally, the link with sequence stratigraphy, and a modern analogue of the Dam Formation. A final chapter (Chapter 6), presents the summary of the results found on this study, answers the objectives, and is followed by the recommendations that will help to for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 Geological Background

The largest distributions of Miocene rocks are exposed in the eastern and northeastern parts of the Arabian Peninsula (Ziegler, 2001). The Miocene formations are distributed from the western United Arab Emirates (UAE), south of Qatar, eastern province of Saudi Arabia, to the southeast of Kuwait and Iraq (Figure 2.1).

Geologically, the study area is located within the Miocene and Pliocene sedimentary rock terrain (Figure 2.1). Miocene and Pliocene rocks in Eastern Saudi Arabia consist of three formations. From the oldest to the youngest (Figure 2.2), these are: (1) the Lower Miocene Hadrukh Formation, (2) the Lower Miocene (Burdigalian) Dam Formation, and (3) the Upper Miocene to Lower Pliocene Hofuf Formation. In general, the three formations are characterized by sandstone, marl, sandy limestone, clay, conglomerate, and thin gypsum layers (locally) indicating continental to shallow marine environments (Ziegler, 2001).

The Dam Formation lies disconformably on the Lower Miocene Hadrukh Formation (calcareous to silty sandstone and sandy limestone), and is in turn disconformably overlain by the sandstone of the Hofuf Formation (Figure 2.2). In the Dammam Dome area, the Dam Formation unconformably overlies either Eocene the Rus or the Dammam Formation (Weijermars, 1999).

As a consequence of a major Neogene transgression over unconformity surfaces, produced by a pre-Neogene episode of erosion and non-deposition, the Dam Formation was deposited in a restricted carbonate platform environment (Ziegler, 2001). This took place in a setting within the Zagros foreland and foredeep basins (Figure 2.3) during the collision between the Arabian and Eurasian plates along the Zagros Thrust Zone. The collision between these two plates resulted from the separation and the movement of the Arabian plate from the African plate (Figure 2.2) which started in the Oligocene time (30 Ma, Sharland et al., 2001). The deposition of the Dam Formation took place in very shallow tidal-flat setting under warm climatic hypersaline conditions, as suggested by the existence of shallow marine, warm-water fossils such as stromatolites, shallow benthic foraminifera, corals and mollusks (Powers *et al*., 1966, Tleel, 1973, Irtem, 1987). The collision between the Arabian and Eurasian plates led to the uplift of the region and caused the deposition of a huge amount of continental supply within the foredeep and foreland basin (Ziegler, 2001) (Figure, 2.3).

The Burdigalian Dam Formation in Saudi Arabia is regionally equivalent to the main hydrocarbon reservoir (Al-Juboury and McNann, 2008) of the Fatha Formation (previously Lower Fars) in SE Iraq and Kuwait, Jebel Cap in Bahrain, the Dam Formation in Qatar and Western UAE, and the Gachsaran (Lower Fars) Formation in offshore UAE (Figures 2.3 and 2.4).

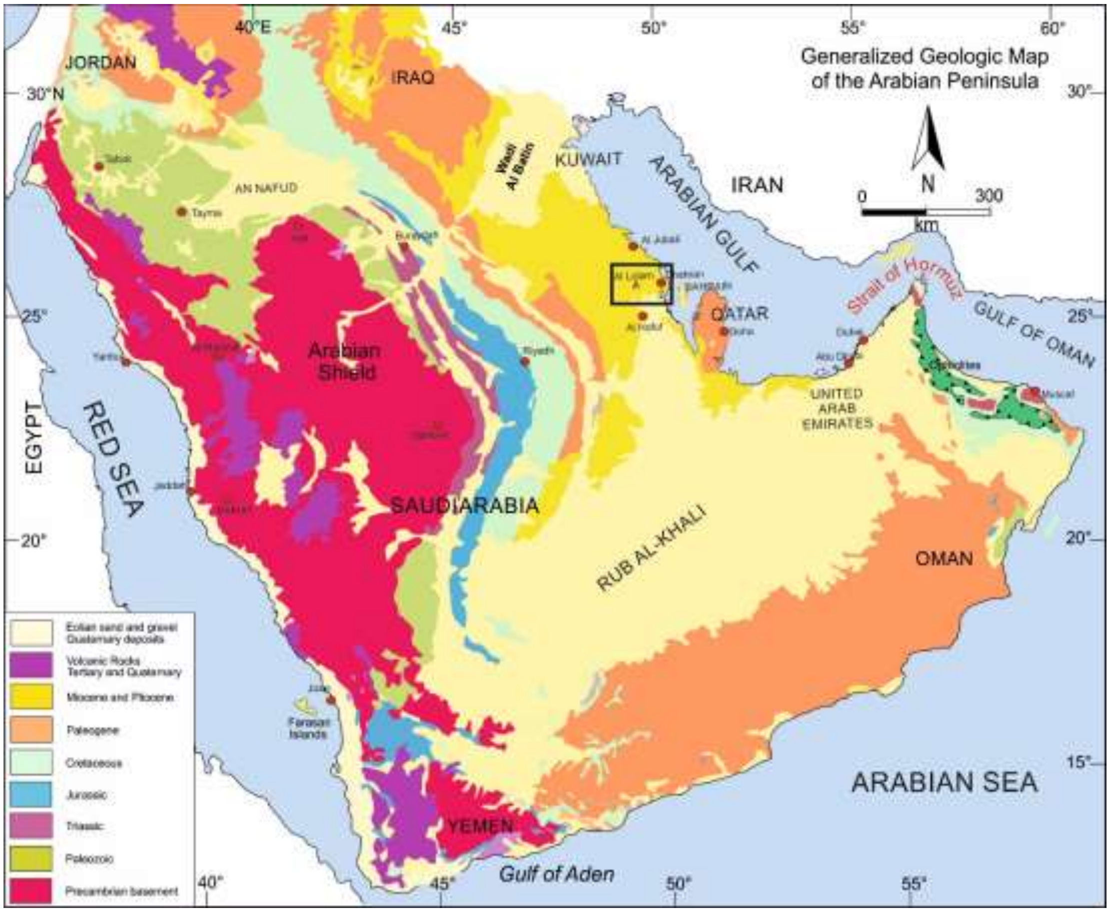


Figure 2.1 Generalized geology of the Arabian Peninsula (after Le Nindre et al. 2003), showing the Miocene and Pliocene rocks distributed in the eastern part of Saudi Arabia. Study area is indicated by a black box.

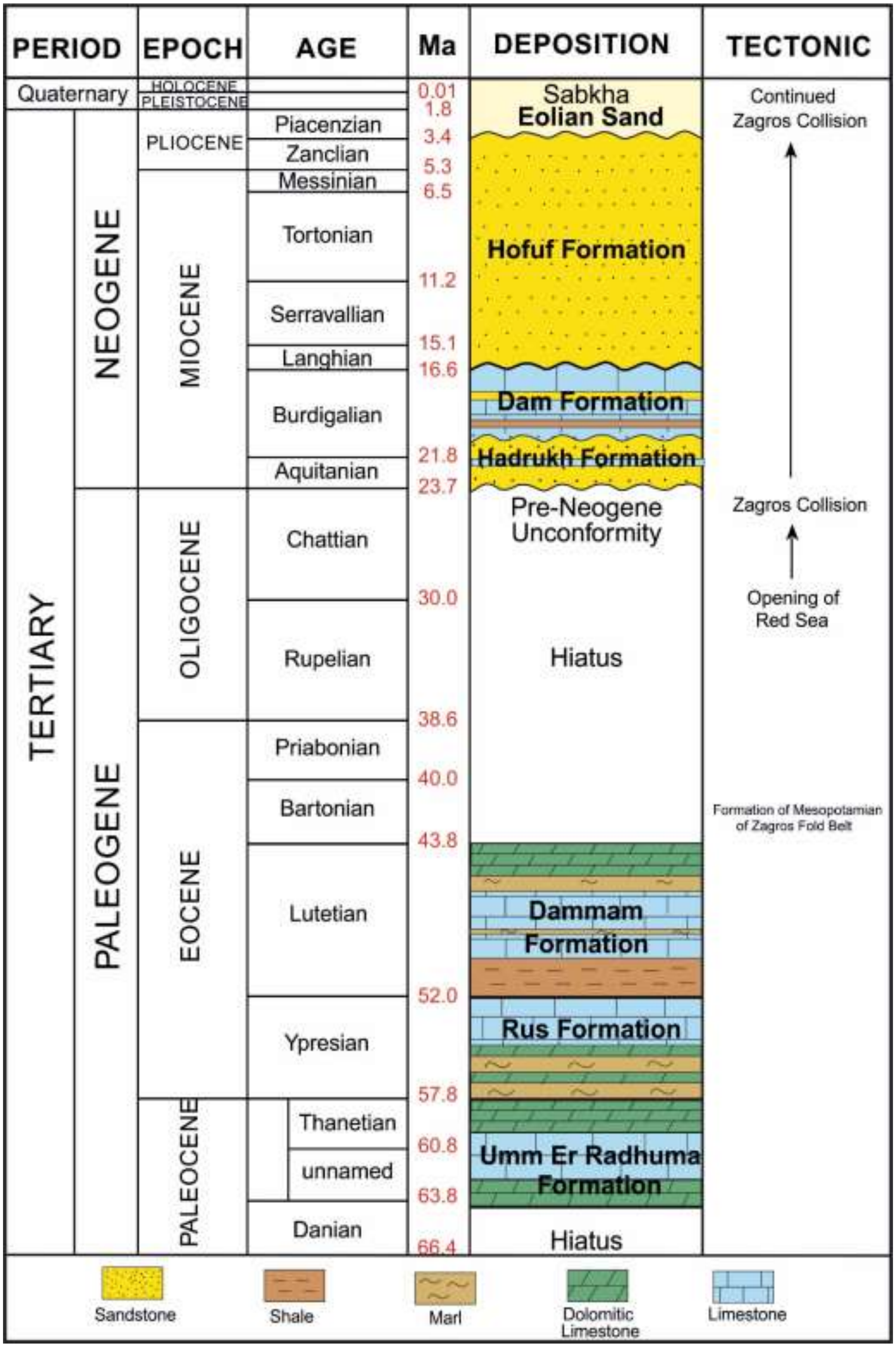


Figure 2.2 Lithostratigraphic column of Cenozoic formations in Eastern Saudi Arabia (modified from Weijermars. 1999).

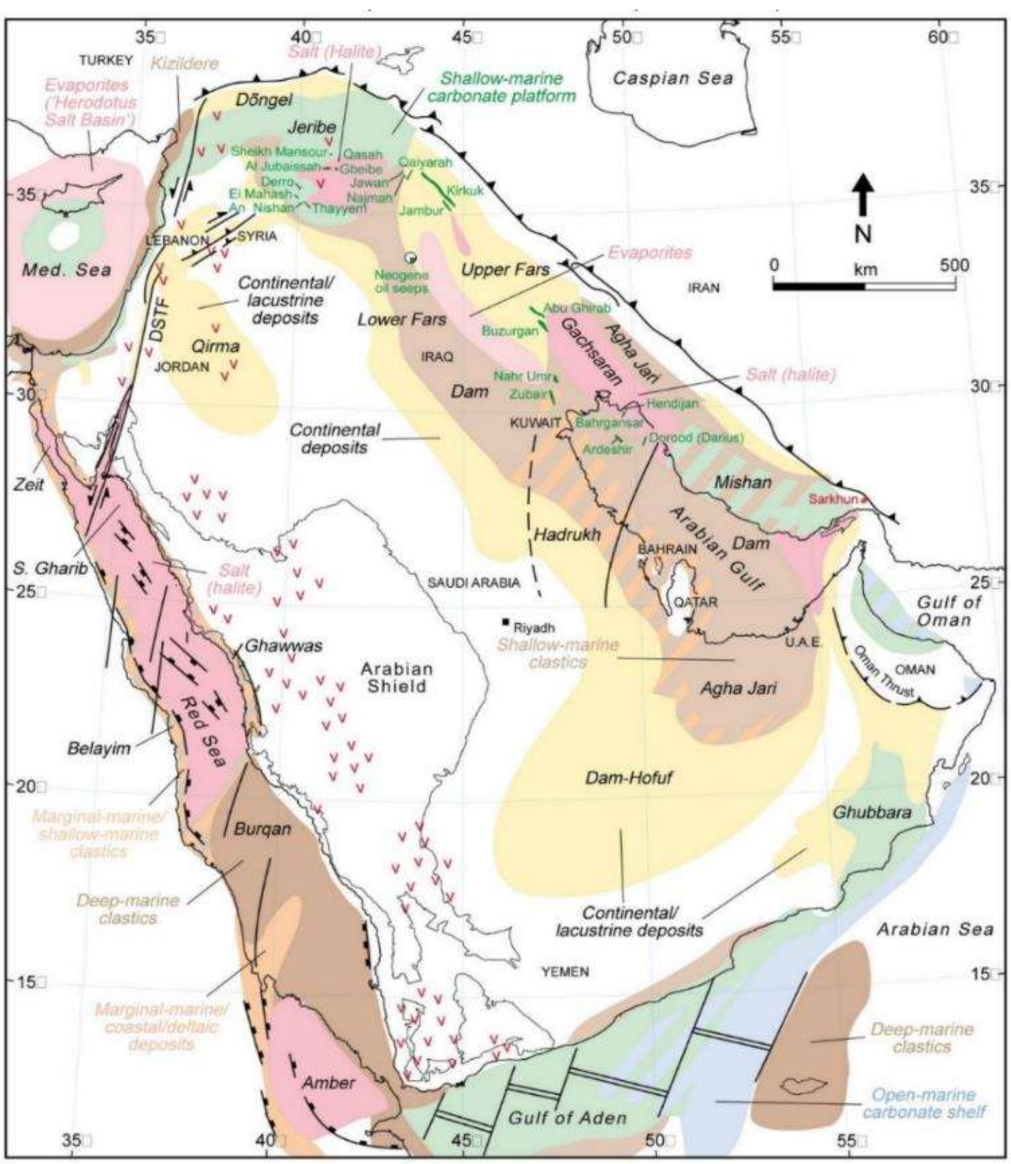


Figure 2.3 Paleofacies map of the Miocene (23.8–5.3 Ma) showing the distribution of the Hadrukh, Dam, and Hofuf formations and the Miocene formations in the Arabian Gulf (Ziegler, 2001).

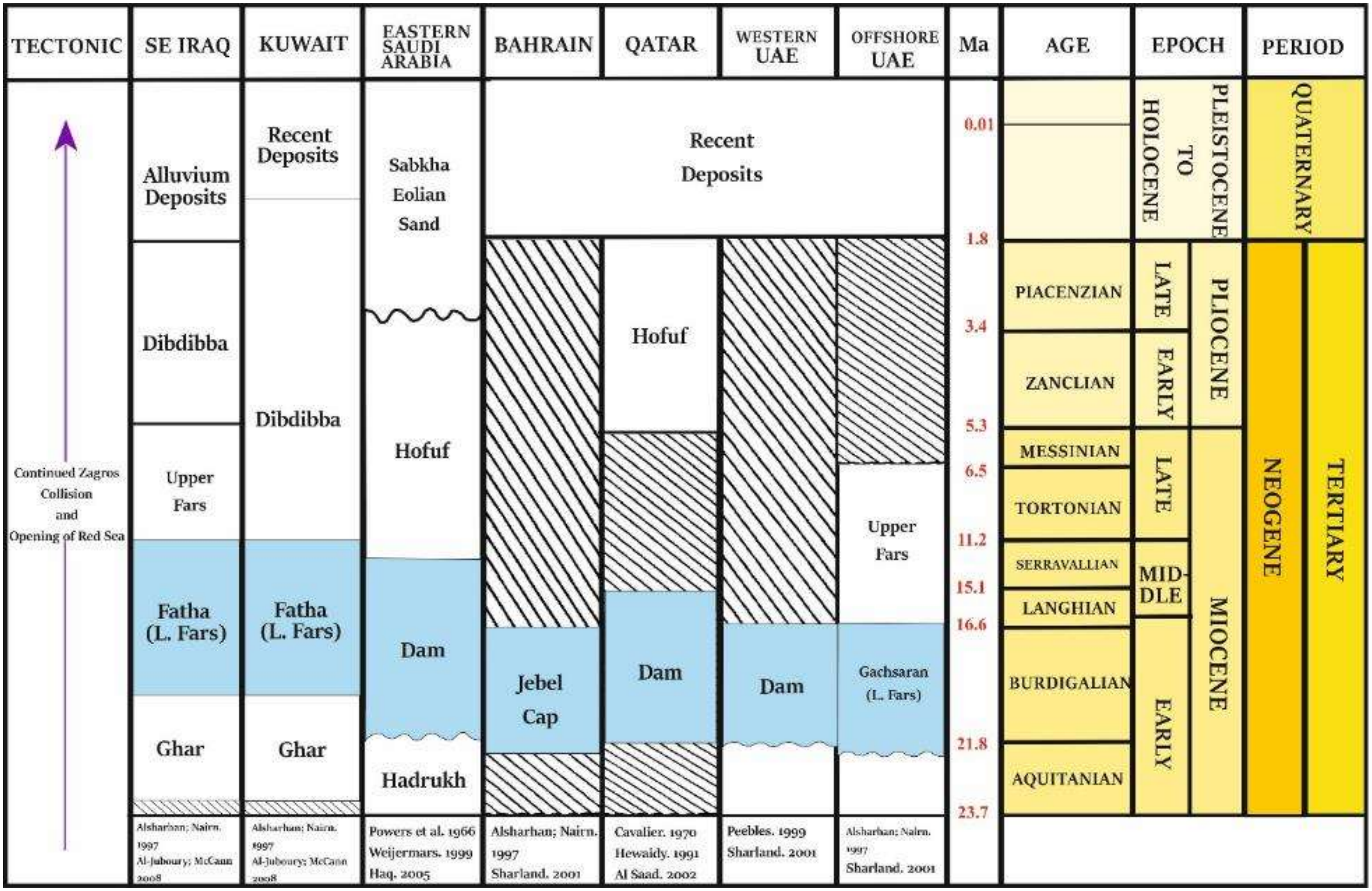


Figure 2.4 Regional correlation of the Neogene formations in the Arabian Gulf (modified from Alsharhan and Nairn, 1995, 1997).

2.2 Previous Studies on the Dam Formation

During his expedition across the central and eastern Arabia, Philby (1933) reported the first fossils (mollusc) occurences from the Miocene rocks of Eastern Saudi Arabia (now known as the Dam Formation).

Steineke and Koch (1935) informally established the name Dam Formation in an unpublished Aramco report. This name was formalized by Thralls and Hasson (1956) and Steineke et al. (1958) in Powers *et al*. (1966). The name is derived from the Jabal Al-Lidam (26°21'N, 49°27'E) where the lower part of this formation is exposed. The upper part has been measured relatively southern Jabal Al-Lidam in Al Umayghir (26°17'N, 49°30'E) (Figure 1.1).

Powers *et al*. (1966) described the Dam Formation at its type locality. The base of the Dam Formation is underlain by sandstone of the Hadrukh Formation, which is characterized by the benthic foraminifera *Archaias* sp. and the echinoid *Echinocyamus* sp. (Figure 2.5). At its type locality, the Dam Formation is composed of pink to red, white, gray marl layers, red, olive grey, and green clay layers, interbedded with sandstone, coquina and chalky limestone (Figure 2.5). Powers *et al*. (1966) also reported the presence of macro- and microfossils within the Dam Formation these fossils include; molluscs, echinoderms, corals, ostracods, vertebrate fragments, crab claws, fossil wood, and foraminifera such as miliolids, *Archaias angulatus*, *Archaias* sp, *Elphidium* sp, *Operculina* sp, *Peneroplis* spp, *Quinqueloculina* spp., and *Triloculina* sp.

Cavalier (1970) subdivided the Dam Formation into two sub-formations in Qatar (a lower sub-formation and an upper sub-formation). Abu-Zied and Khalifa (1983) modified Cavalier's work and subdivided the Dam Formation into A and B Members.

Tleel (1973) conducted detailed investigations on the Dam Formation in the Dammam Dome (Jabal Midra Al-Junubi). He reported the following fossils, *Archaias angulatus, Borelis melo, Echinocymis* sp*, Peneroplis farensis, Sorites orbiculus, Taberina malabarica,* and miliolids within the formation. In general, the Dam Formation in the Dammam Peninsula consists of coral algal reef facies, molluscan-rich facies, and calcarenite facies.

Irtem (1986) conducted a detailed study on the occurrence of stromatolites in the basal part of the Dam Formation in the Al Lidam area. He reported that in general, the Dam Formation consists of three deepening-upward cycles that were deposited under hypersaline conditions in supratidal, intertidal, and subtidal environments for interbedded detrital and carbonate rock, and shallow subtidal to lower intertidal environment for stromatolites associated with oolitic grainstone.

Hewaidy (1991) studied the foraminifera within the Dam Formation in Qatar in the Al-Kharrara and Al-Nakhash area, and assigned the formation to an Early-Middle Miocene age (Burdigalian to "Helvetian"). Khalifa and Mahmoud (1993) reported three different types of algal stromatolites deposited in a protected tidal environment within the B member at Khashm Al-Nakhash.

Weijermars (1999) conducted a detailed study on the outcrops of the Dam Formation at three locations; (1) Jebel Umm Er Rus, (2) Jebel Midra Ash Shamali, and (3) Jebel Midra Al-Janubi within the Dammam Dome area. Jebel Umm Er Rus, the basal unit of the Dam Formation overlies the Midra Shales and comprises of microcrystalline sandy limestone with pink to purple stromatolitic limestone resting on the top of basal sandy limestone beds. At Jebel Midra Ash Shamali, the basal Dam Formation consists of colored conglomerate, which contains boulders from the Khobar Limestone with sandy and argillaceous limestone as matrix. The

Dam Formation rests disconformably on the top of the Rus Formation at Jebel Midra Al-Janubi. It is characterized by bivalves and gastropods, blue-green algal, and a bioherm reef facies that contains *in situ* corals. In the Dammam peninsula, the Dam Formation represents deposition in a shallow-marine environment with fluctuating sea-levels.

Al-Saad and Ibrahim (2002) measured three surface stratigraphic sections in southwestern Qatar (Al-Nakhash area) and subdivided the Dam Formation into two new members. These are (1) the lower Al-Kharrara Member which is composed of calcareous claystone, marl, dolomitic limestone, and arenitic limestone. (2) The upper Al-Nakhash Member, mainly composed of chalky, gypsiferous, and stromatolitic limestone. In general, the formation consists of four major lithofacies units (limestone, marls, clay, and evaporites) and six limestone subfacies. The faunas dominant within these two members are bivalves, gastropods, stromatolites, and foraminifera. The foraminiferal assemblages are represented by 38 species, 29 genera, and 14 families (Table 2.1). Milioline genera, including *Agglutinella, Archaias, Dendritina, Peneroplis, Pygro, Sigmoilina, Spirolina, Triloculina, and Quinqueloculina*, were dominant within this formation. It is assigned a Burdigalian (Early Miocene) age due to the presence of *Borelis melo melo.* Based on the lithofacies and faunal assemblages, the Dam Formation was deposited under warm climatic (25° to 30°C) conditions in a very shallow tidal flat setting, 0-35 m deep for the lower member and 0 – 10 m deep for the upper member with a salinity ranging between 35 and 50 ppt. The Al-Nakhash (upper) member is equivalent to the Dam Formation of the Dammam Dome based on the abundance of *Borelis melo melo* and stromatolitic limestone.

Al-Enezi (2006) compared samples of recent foraminifera from the nearshore of Arabian Gulf with the foraminiferal species from the carbonate of the Dam Formation at Jabal Midra Al-

Junubi.The study found out that the foraminiferal assemblages in the Dam Formation at the Dammam Dome are similar to the modern foraminifera from the Arabian Gulf. Recent foraminiferal assemblages were used to interpret the depositional environment of each biofacies of the Dam Formation at Jabal Midra Al-Junubi based on the morphological similarity between the species. The foraminiferal species within this formation consist of (Table 2.1) three agglutinated species (*Textularia* spp., *Schlumbergerina* sp. and *Reophax* spp.) and 37 miliolid species. The miliolids include 16 species of *Quinqueloculina* spp, 8 species of *Triloculina* spp, 4 species of *Spiroloculina* spp, *Archaias hensoni, Alveolinella* sp., *Borelis melo melo, Massilina* spp, *Peneroplis* spp., *Peneroplis pertusus, Sorites* sp., *and Spirolina* spp. Eleven rotaliid taxa (*Ammonia* spp., *Cibicides* spp., *Elphidium* spp., *Nonion* spp., *Operculina* sp., *Planorbulina larvata, Rotalia* spp., and rotaliid spp.) were also identified. *Ammodiscus* sp., and *Ammobaculites* sp. were the agglutinated foraminifera encountered in the study. The presence of *Borelis melo melo* throughout the measured section suggests a Middle Miocene age. This outcrop has, unfortunately, been removed due to construction.

The micropalaeontology of the Rus, Dammam and Dam formations, as exposed on the Dammam Dome of Saudi Arabia was presented in two posters by Hughes (2008). He assigned age of Dam Formation on studied area as a Middle Miocene based on the presence of *Taberina malabarica* and *Borelis melo*.

Le Blanc (2009) performed surface geological mapping and macropaleontological investigations of the Dam Formation in Qatar. The macrofossils contents of the facies consist of vertebrates (shark teeth, mammals, reptiles), and marine invertebrates (arthropods, echinoderms, corals, bryozoa, molluscs, bivalvia, gastropods, and stromatolites).

Al-Khaldi (2009) conducted a detailed sequence stratigraphic investigation with seven measured stratigraphic sections from one large outcrop in the Al-Lidam area. He concluded with three composite sequences; CS1, CS2, CS3, four high frequency sequences; HFS1, HFS2, HFS3, HFS 4, and 17 sequences cycles. Al-Khaldi proposed that the cross-bedded sandstone facies (estuarine fill) and microbial banks were deposited during a transgressive system track (TST) while skeletal grainstones were deposited in the highstand system track (HST).

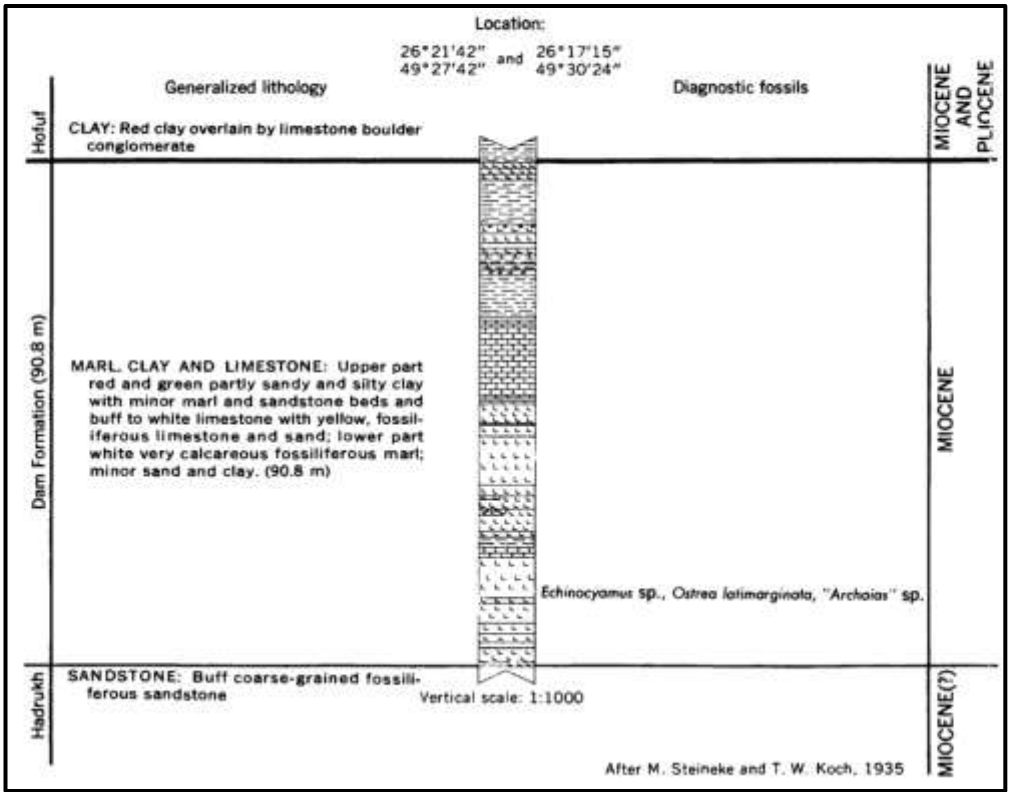


Figure 2.5 Detailed measured section in type locality of the Dam Formation by Steineke and Koch (1935, in Powers et al. 1966).

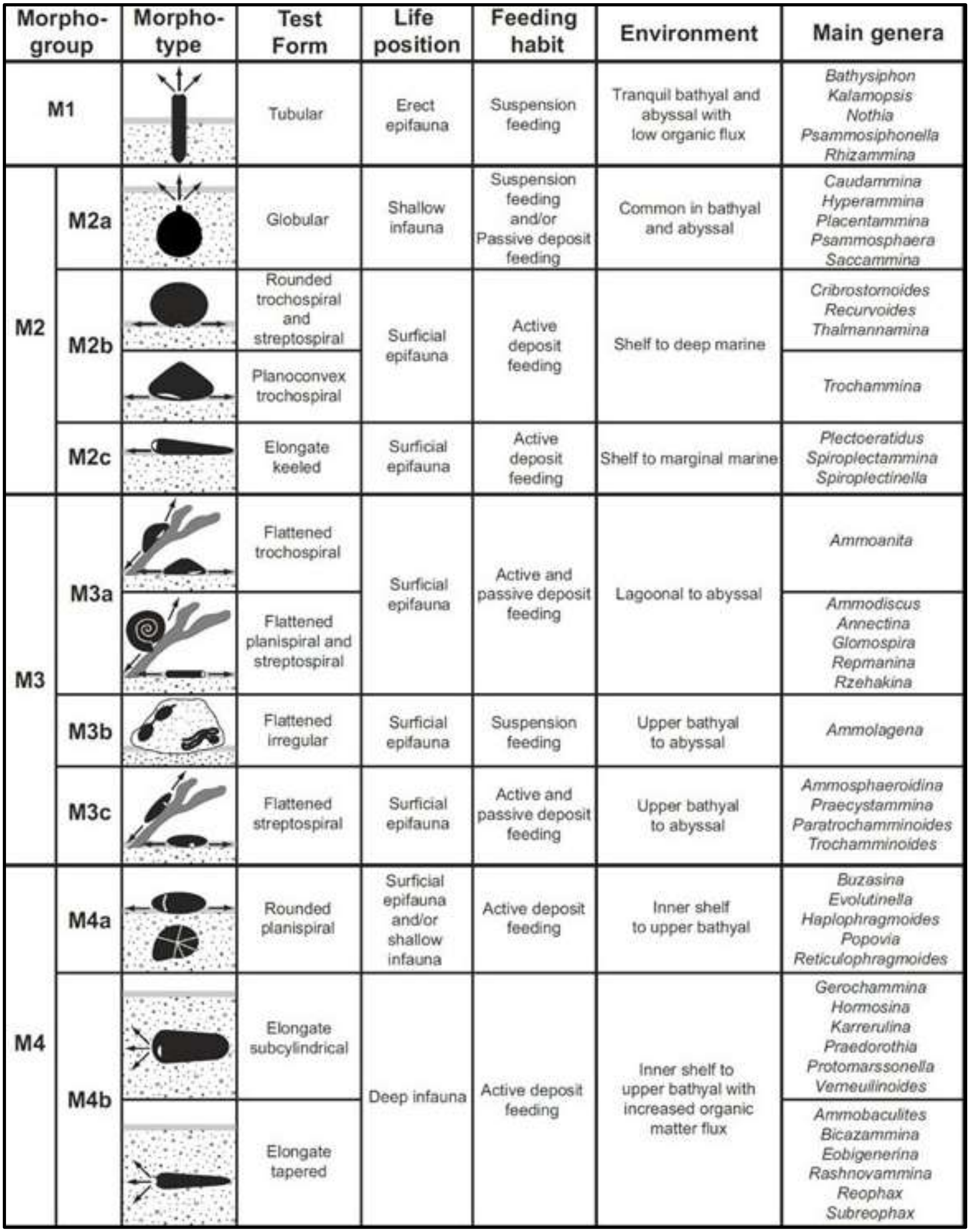
Table 2.1 Previous study reported foraminiferal assemblages within the Dam Formation from different localities.

Dammam Dome (Tleel 1973; Al Enezi 2006)	**Southwestern Qatar (Al-Saad and Ibrahim 2002)**	
Jabal Midra Al-Junubi	**Al-Nakhash Member (Upper)**	**Al-Kharrara Member (Lower)**
Alveolinella sp. *Ammonia* spp. *Ammodiscus* sp. *Ammobaculites* sp. *Archaias hensoni.* *Borelis melo melo.* *Cibicides* spp. *Elphidium* spp. *Massilina* spp. *Nonion* spp. *Operculina* sp. *Peneroplis* spp, *Peneroplis pertusus.* *Planorbulina larvata.* *Quinqueloculina* spp. *Reophax* spp. *Rotalia* spp. *Schlumbergerina* sp. *Sorites* sp. *Spirolina* spp, *Textularia* spp. *Triloculina* spp. *Spiroloculina* spp.	*Amphisorus sp.* *Archiacina spp.* *Borelis melo melo* *Cibicidoides unbonatus* *Cibroelphidium spp.* *Elphidium crispum.* *Lenticulina* cf. *rotulata.* *Peneroplis carinata.* *Peneroplis cristata.* *Quinqueloculina bicarinata.* *Quinqueloculina. lamarchiana.* *Sigmoilina sp.* *Spirolina arietina.* *Triloculina. subgranulata.* *Triloculina trigonula.* Bryzoa Fish teeth	*Agglutinella* spp. *Ammonia beccarii.* *Amphisorus* sp. *Archaias* sp. *Archiacina* sp. *Quinqueloculina bicarinata.* *Borelis melo melo.* *Cancris auricular.* *Cibicides* sp. *Cibicidoides* spp. *Cibroelphidium* spp. *Clavulina cf. mexicana* *Clavulinoides* sp. *Coscinospira* spp. *Dendritina* spp. *Elphidium* sp. *Haplophragmoides* sp. *Lenticulina* cf. *rotulata.* *Miliolinella* sp. *Peneroplis carinata.* *Peneroplis cristata.* *Proemassilina rugosa.* *Pyrgo laevis.* *Pyrgo* spp. *Quinqueloculina bicarinata.* *Quinqueloculina lamarchiana* *Quinqueloculina* spp. *Sigmoilinita tenuis.* *Spiroloculina excavata.* *Spirolina arietina.* *Triloculina linneiana.* *Triloculina trigonula.* *Triloculinella* sp. Ostracods Fish teeth

2.3 Morphogroup Analysis

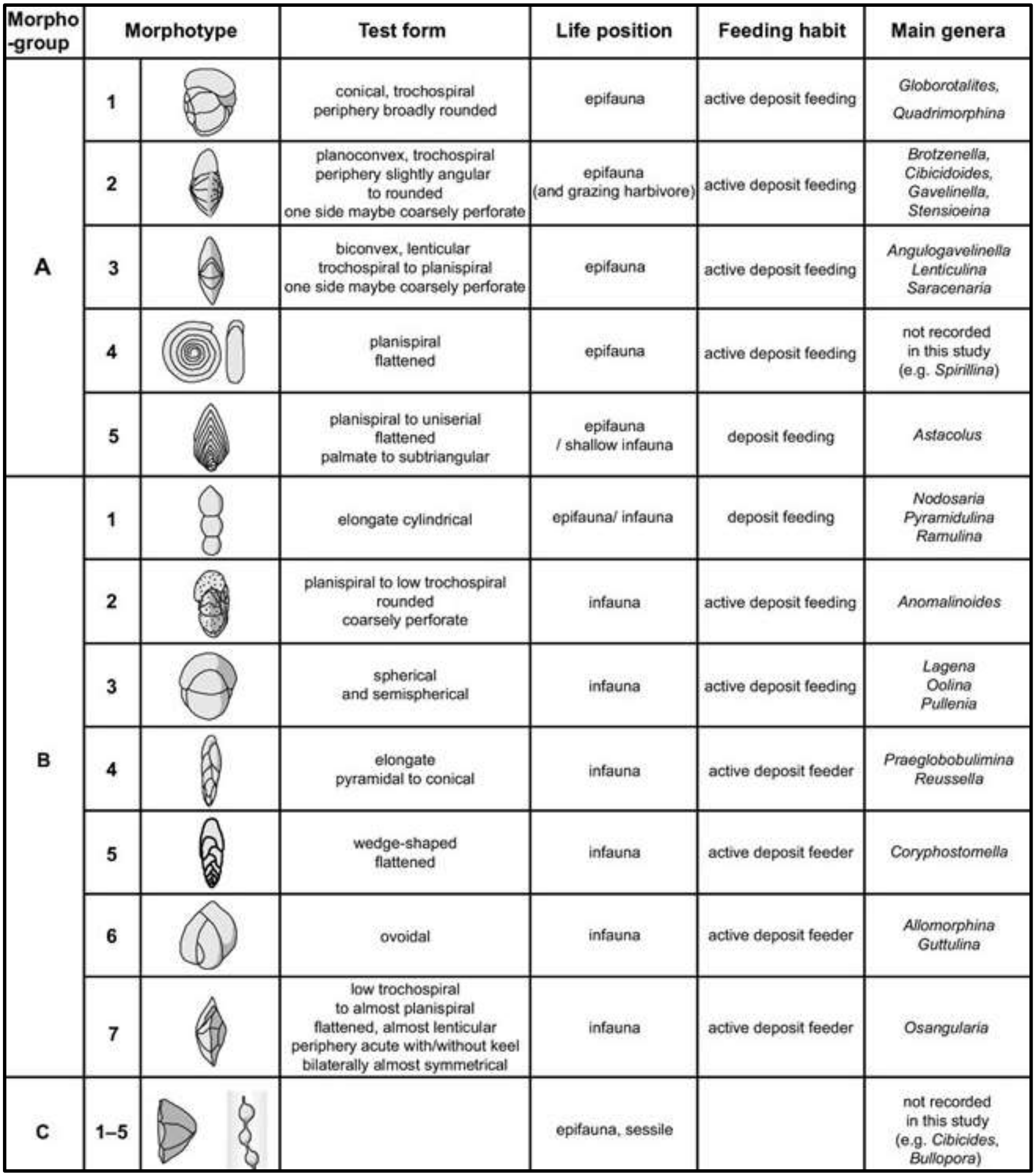
Morphogroup analysis on benthic foraminifera in shallow and deep water settings for both calcareous benthic and agglutinated foraminifera has been developed and investigated by many micropaleontologists (Jones and Charnock 1985; Bernhard, 1986; Corliss and Chen, 1988; Tyszka and Kaminski, 1995; Nagy et al., 1992, 1995, 2009; Kaminski and Gradstein, 2005; Reolid et al., 2008, 2013; Alperin et al. 2011, Setoyama et al. 2011, 2013). Changes in the proportions of the morphogroups are used to semi-quantitatively assess palaeobathymetric trends and palaeoenvironmental changes as reflected by the shape and distribution of foraminifera without considering the species-level taxonomy. This approach has only been applied in Saudi Arabia to the Shu'aiba Formation (Hughes, 2005).

The concept of morphogroup analysis is based on the functional morphology of the foraminiferal test with an assumption that, changes in environmental condition will change the relative abundance of morphogroup assemblages due to the fact the different foraminifera test forms have different life habitats (epifauna and infauna), and feeding strategies (Corliss, 1985; Jones and Charnock, 1985; Murray et al. 2011). Figure 2.6 shows the classification of agglutinated and calcareous benthic foraminiferal morphogroups and morphotypes based on a Late Cretaceous example (Setoyama, 2012).



Morpho-group	Morpho-type	Test Form	Life position	Feeding habit	Environment	Main genera
M1		Tubular	Erect epifauna	Suspension feeding	Tranquil bathyal and abyssal with low organic flux	*Bathysiphon* *Kalamopsis* *Nothia* *Psammosiphonella* *Rhizammina*
M2	M2a	Globular	Shallow infauna	Suspension feeding and/or Passive deposit feeding	Common in bathyal and abyssal	*Caudammina* *Hyperammina* *Placentammina* *Psammosphaera* *Saccammina*
	M2b	Rounded trochospiral and streptospiral	Surficial epifauna	Active deposit feeding	Shelf to deep marine	*Cribrostomoides* *Recurvoides* *Thalmannamina*
		Planoconvex trochospiral				*Trochammina*
	M2c	Elongate keeled	Surficial epifauna	Active deposit feeding	Shelf to marginal marine	*Plectoeratidus* *Spiroplectammina* *Spiroplectinella*
M3	M3a	Flattened trochospiral	Surficial epifauna	Active and passive deposit feeding	Lagoonal to abyssal	*Ammoanita*
		Flattened planispiral and streptospiral				*Ammodiscus* *Annectina* *Glomospira* *Repmanina* *Rzehakina*
	M3b	Flattened irregular	Surficial epifauna	Suspension feeding	Upper bathyal to abyssal	*Ammolagena*
	M3c	Flattened streptospiral	Surficial epifauna	Active and passive deposit feeding	Upper bathyal to abyssal	*Ammosphaeroidina* *Praecystammina* *Paratrochamminoides* *Trochamminoides*
M4	M4a	Rounded planispiral	Surficial epifauna and/or shallow infauna	Active deposit feeding	Inner shelf to upper bathyal	*Buzasina* *Evolutinella* *Haplophragmoides* *Popovia* *Reticulophragmoides*
	M4b	Elongate subcylindrical	Deep infauna	Active deposit feeding	Inner shelf to upper bathyal with increased organic matter flux	*Gerochammina* *Hormosina* *Karrerulina* *Praedorothia* *Protomarssonella* *Verneuilinoides*
		Elongate tapered				*Ammobaculites* *Bicazammina* *Eobigenerina* *Rashnovammina* *Reophax* *Subreophax*

Figure 2.6 Agglutinated (A) and Calcareous benthic foraminifera (B) morphogroups and morphotype (from Setoyama, 2012).



Morpho -group	Morphotype		Test form	Life position	Feeding habit	Main genera
A	1		conical, trochospiral periphery broadly rounded	epifauna	active deposit feeding	*Globorotalites, Quadrimorphina*
	2		planoconvex, trochospiral periphery slightly angular to rounded one side maybe coarsely perforate	epifauna (and grazing harbivore)	active deposit feeding	*Brotzenella, Cibicidoides, Gavelinella, Stensioeina*
	3		biconvex, lenticular trochospiral to planispiral one side maybe coarsely perforate	epifauna	active deposit feeding	*Angulogavelinella Lenticulina Saracenaria*
	4		planispiral flattened	epifauna	active deposit feeding	not recorded in this study (e.g. *Spirillina*)
	5		planispiral to uniserial flattened palmate to subtriangular	epifauna / shallow infauna	deposit feeding	*Astacolus*
B	1		elongate cylindrical	epifauna/ infauna	deposit feeding	*Nodosaria Pyramidulina Ramulina*
	2		planispiral to low trochospiral rounded coarsely perforate	infauna	active deposit feeding	*Anomalinoides*
	3		spherical and semispherical	infauna	active deposit feeding	*Lagena Oolina Pullenia*
	4		elongate pyramidal to conical	infauna	active deposit feeder	*Praeglobobulimina Reussella*
	5		wedge-shaped flattened	infauna	active deposit feeder	*Coryphostomella*
	6		ovoidal	infauna	active deposit feeder	*Allomorphina Guttulina*
	7		low trochospiral to almost planispiral flattened, almost lenticular periphery acute with/without keel bilaterally almost symmetrical	infauna	active deposit feeder	*Osangularia*
C	1–5			epifauna, sessile		not recorded in this study (e.g. *Cibicides, Bullopora*)

Figure 2.7 Calcareous benthic foraminifera morphogroups and morphotype (Setoyama, 2012).

2.4 Miocene Paleogeography

The Mediterranean Sea, Paratethys, and Indo-Pacific Ocean were connected in the Early Oligocene to the Middle Miocene (Figure 2.7). Due to sea-level change (transgression and regression) combined with tectonic activity, throughout this time the marine connection to the north opened and closed intermittently (Reuter *et al*. 2007).

The opening and closing of the Tethyan seaways changed the area from continental to open marine conditions. This was the time that the tropical-subtropical marine fauna migrated from the Indian Ocean to the Mediterranean and Paratethys during the sea-level rise, and mammals migrated during the sea-level fall through the land bridge which connected Africa and Eurasia, known as the *Gomphotherium* landbridge (Rögl 1999). The Tethyan Ocean was then completely closed in the Late Miocene time as a result of the collision between the African/Arabian Plate and Eurasian Plates.

Based on studies carried out by Al Saad and Ibrahim (2002), and Al Eneezi (2006) which assigned a Burdigalian age to the Dam Formation, we can conclude therefore that, the Dam Formation was deposited during the time of the connection between the Indian Ocean and the Mediterranean Sea and Paratethys. The marine fauna, in particular foraminifera, in the studied formation might have similarities with those from the Mediterranean and Paratethys. We will compare the assemblage of foraminifera found in studied formation with northwestern Arabia, Iran, Vienna, Romania, and Poland and reconstruct the paleoenvironment during the deposition time (Burdigalian time).

The foraminiferal assemblage from the marine Middle Miocene in the Romanian Carpathian area (Popescu, 1979). The foraminiferal faunal is dominated by shallow marine to deeper marine environment based on the abundances of agglutinated and planktonic foraminifera.

In the central Paratethys (Vienna basin), Cicha (1998) reported that the foraminiferal faunal assemblage is dominated by calcareous benthic, agglutinated, and planktonics, which represents shallow water to deep marine environment.

Gonera (2012) reported foraminiferal faunal from the Burdigalian age and dominated by Miliolina, Rotaliina, with lesser percentages of Lagenina and Textulariina which indicates shallow and normal marine depositional environment in high-energy waters with currents and tidal movements, normal salinity, and warm water habitat in the Polish outer Carpathians basin.

Reuter *et al*. (2007) described the depositional environments ranging from terrestrial, shallow marine (mangrove, seagrass meadow, inner shelf lagoon, reefal) to deep offshore setting from the Middle Miocene Qom Formation in Iran.

Hughes (2014) interpreted the Burdigalian age formation in northwestern Arabia (Red Sea) had been deposited in a shallow and normal marine environment to deep marine setting based on bio-components such as calcareous algae, corals, benthic foraminifera, and planktonic foraminifera that were found in the studied formation.

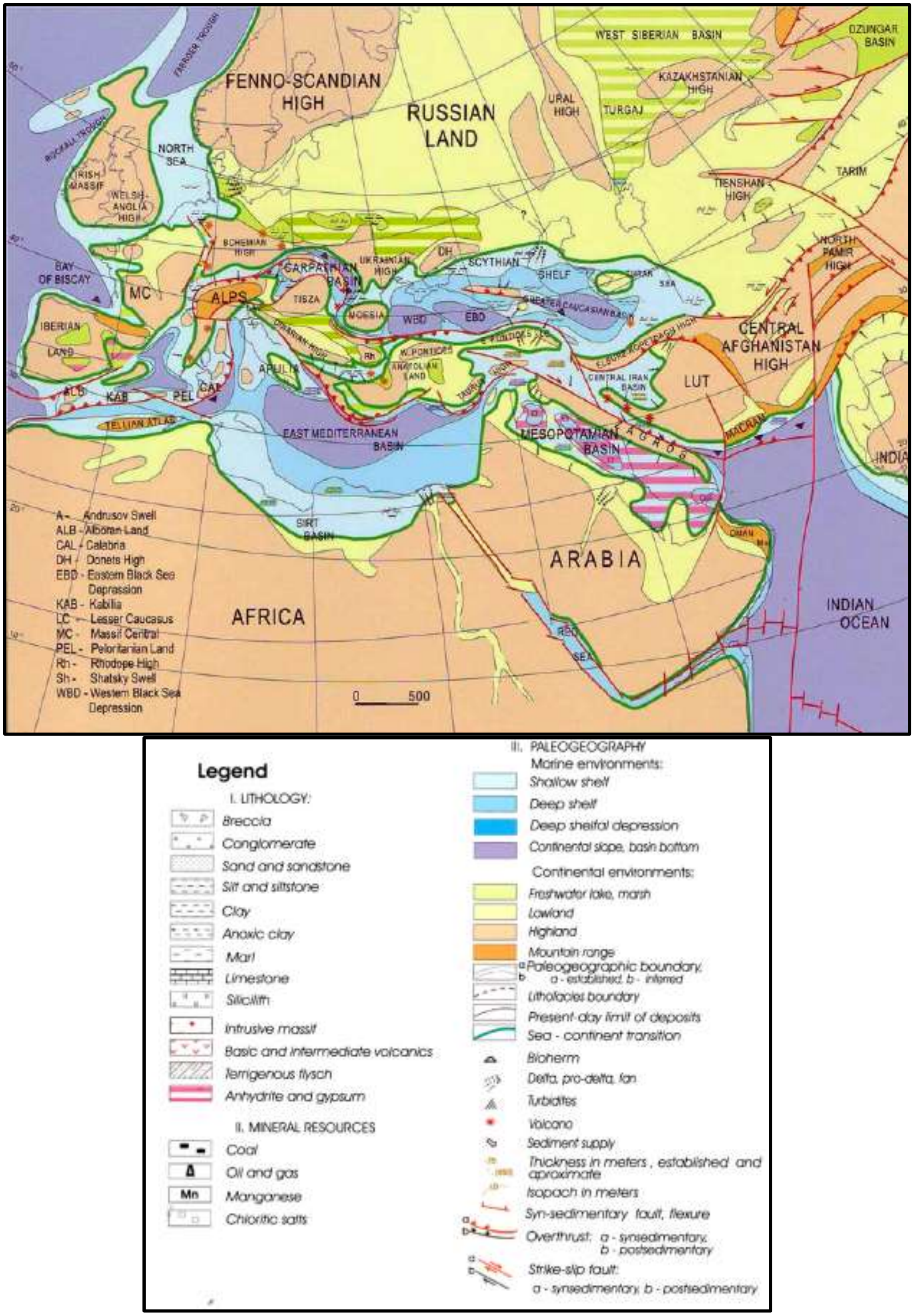


Figure 2.8 Paleogeographic map of Paratethys during early Miocene time (Popov et al. 2004).

CHAPTER 3

METHODOLOGY

In order to achieve the objectives a combination of field investigation and laboratory analyses was used. The workflow of this study is summarized in Figure 3.1.

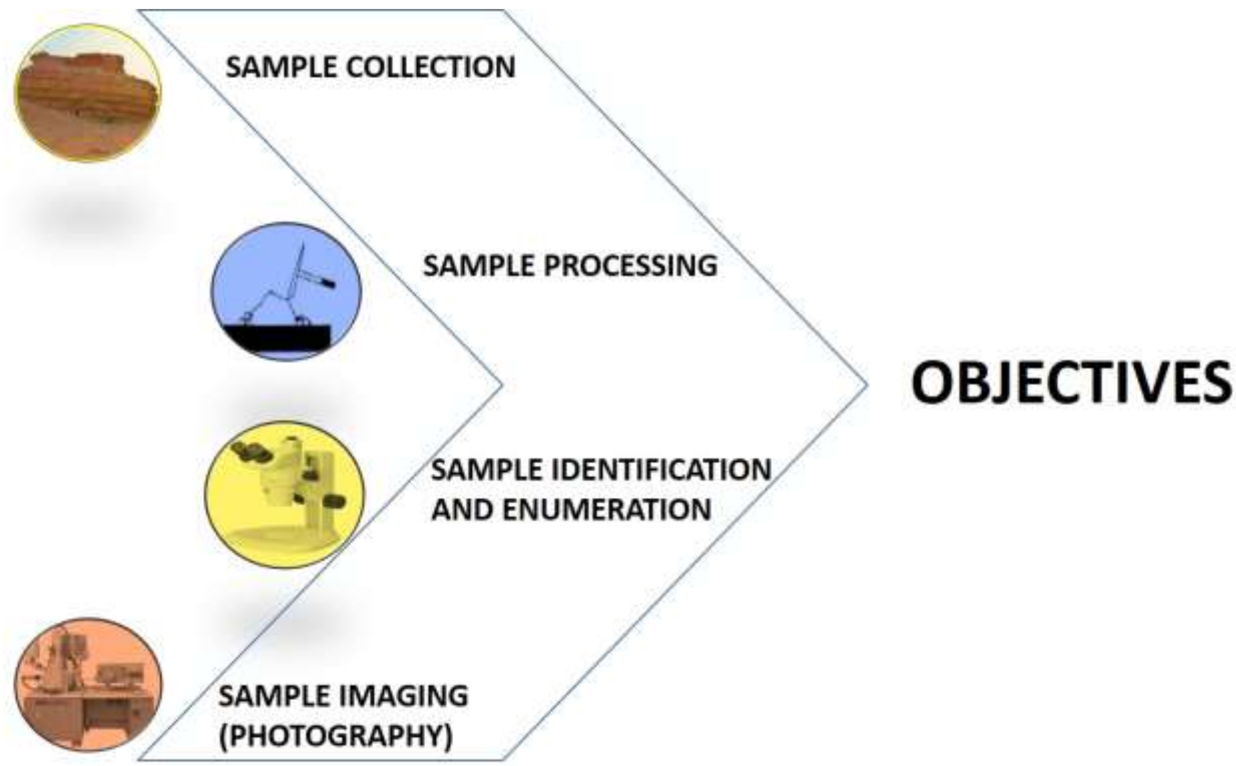


Figure 3.1 Systematic workflow of this study.

3.1 Sample Collection

In total, 80 samples from four outcrops (8, 23, 1, and 2) along the west-east transect direction in the Al-Lidam area were processed and analyzed in this study (Figure 3.2). The main lithology of the samples consists of carbonate, marl, clay, and sandstone. In this study, the same set of samples that have been collected from the field for the sedimentology (Bashri, 2015) was used. The studied samples were collected from every bed respectively. The sample collection depends upon the bedding thickness, one sample is collected from a thin bed (10 to 30 cm) and three samples were collected from a thick bed (more than 70 cm) which represents the lower, middle, and upper parts of the bed respectively.

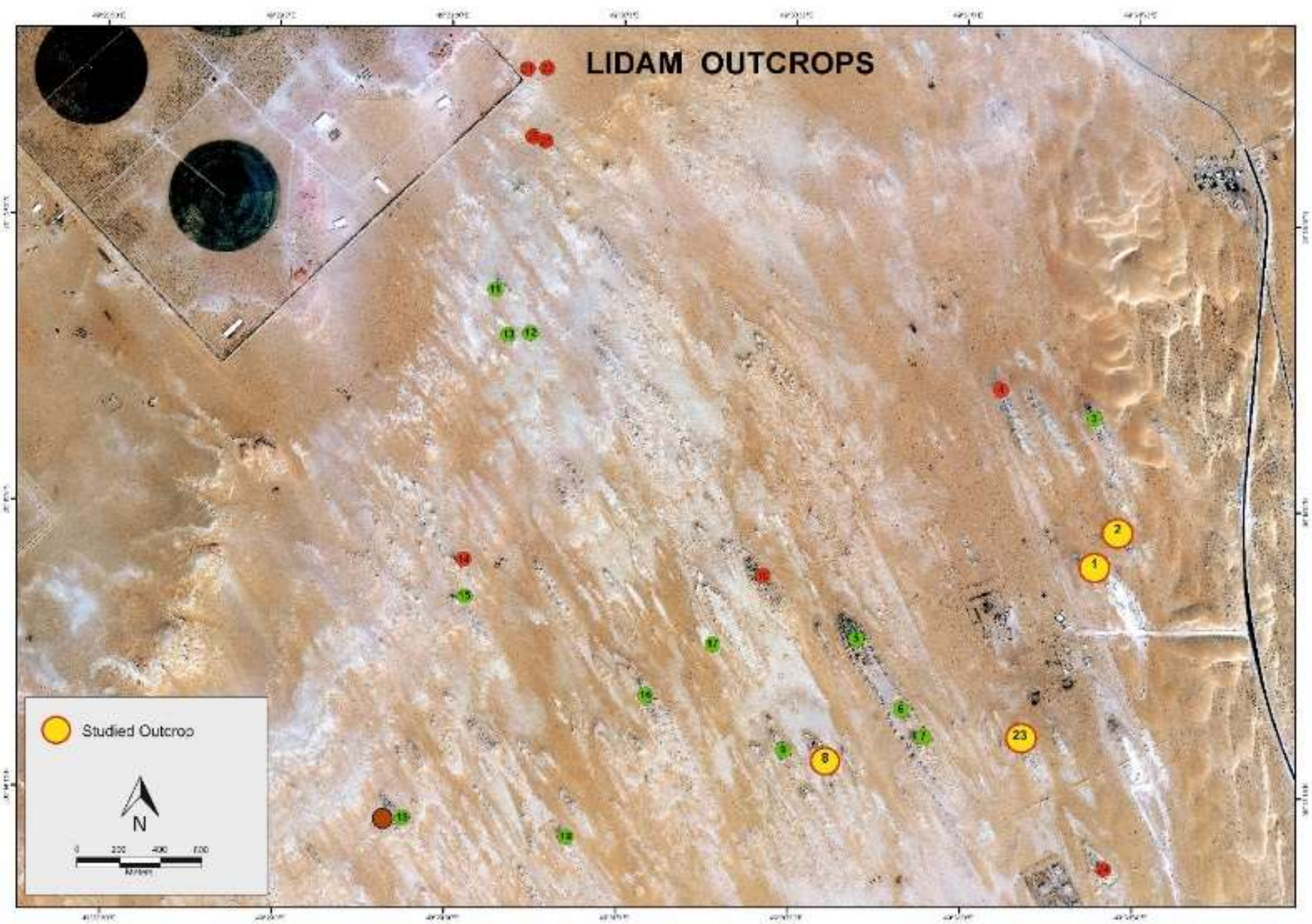


Figure 3.2 Study outcrop location in the Al-Lidam area .

3.2 Sample Processing

The collected samples were processed using standard micropaleontological techniques. Petrographic thin sections were studied in order to determine the lithofacies and biofacies within the carbonate rocks (Figure 4.5). Examining foraminifera in thin section has its limitations. For example, it only allows a one-dimensional view of the specimens, thus making proper taxonomical identification very difficult (Patruno et al., 2011; Coccioni and Premoli-Silva, 2015). This leads to the difficulty in identifying and distinguishing the species and even some genera (Reolid and Herero, 2004). Therefore, we also used the acetic acid treatment to retrieve microfossil from lithified carbonate without destroying the microfossil content (Lirer, 2000; Reolid and Herrero, 2004). The treatment procedure are itemized as follows and also presented in (Figure 3.3).

1) Break 100g of carbonate samples into small fragments of about 5 mm in diameter. The small size of fragments is recommended and will give a better result,
2) Disagregate the crushed samples by soaking solution of 80% acetic acid (CH_3COOH) and 20% distilled water (the level of acetic acid at least 2 cm more than sample level),
3) Leave the sample submerged in a solution for 10 hours to process segregation,
4) Wash the disaggregated sample with abundant water through stainless steel standard sieves with mesh opening 500, 250, 125, and 63 μm,
5) Dry the residue from 125 and 63 μm at low temperature (40-50°C),
6) Transferred to labeled small bottle vials and subsequently pick under binocular stereo-microscope.

Siliciclastic samples (sandstone, clay, and marl) are relatively simple to process compared with carbonate rock. The process is as follows (Figure 3.4):

1) Crush the samples into small pieces (if the samples are too big),
2) Soak the sample in a water and soap solution and boil in a hot plate with temperature around 100° C,
3) Wash the samples through stainless steel standard sieves after sometime with mesh opening 63 microns to remove the clay contents,
4) Repeated steps 2 and 3 for three to four times till the sample are fully disaggregated and free from the clay matrix, and then dried
5) Transfer to labeled small bottle vials and pick under a binocular stereo-microscope.

3.3 Sample Identification

An optical petrographic microscope equipped with digital camera was used for qualitative identification of microfossils from the thin sections. For quantitative identification, the specimens extracted from the carbonate and siliciclastic residues were examined under a binocular stereoscopic microscope. The microfossils were sorted into micropaleontological slides and enumerated. The slides were properly labelled with sample names and sample codes. The well-preserved specimens were photographed using a digital camera mounted on a Nikkon 1500 stereo-microscope in the Geosciences Department at King Fahd University Petroleum and Minerals.

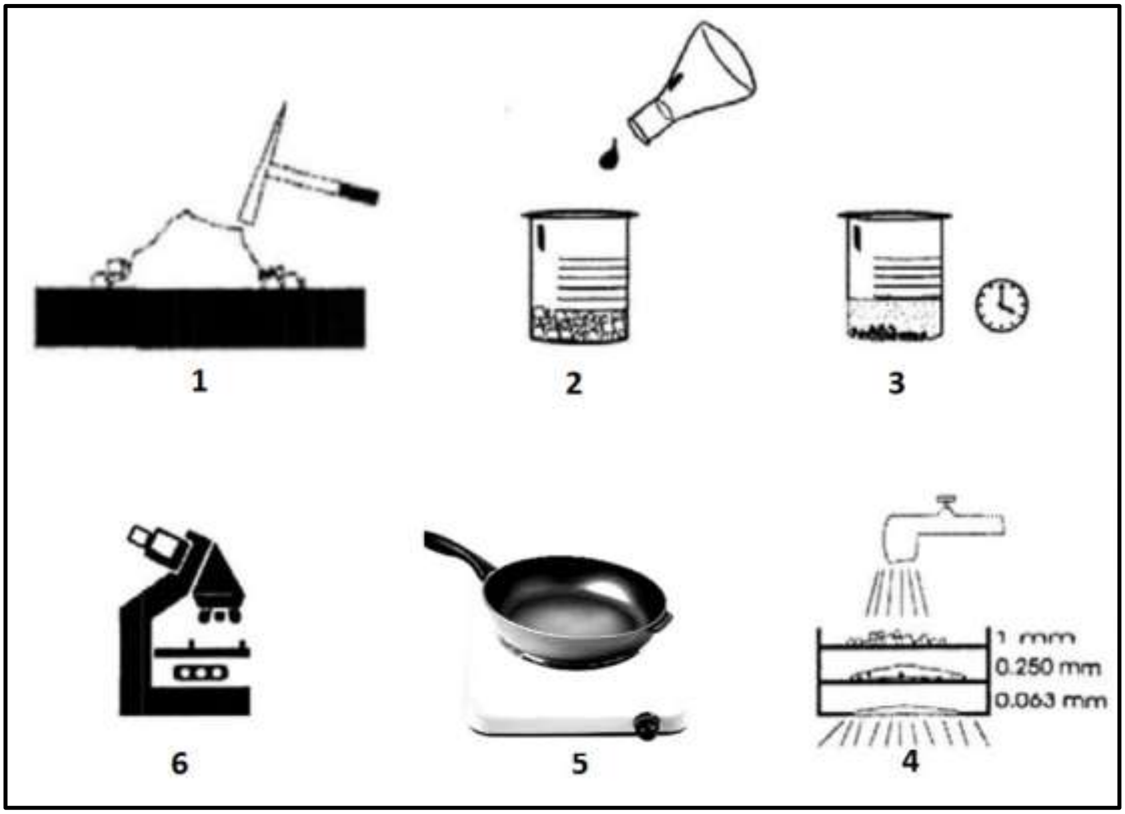


Figure 3.3. Laboratory procedure for retrieving microfossil for carbonate rock using acetic acid (after Lirer. 2000).

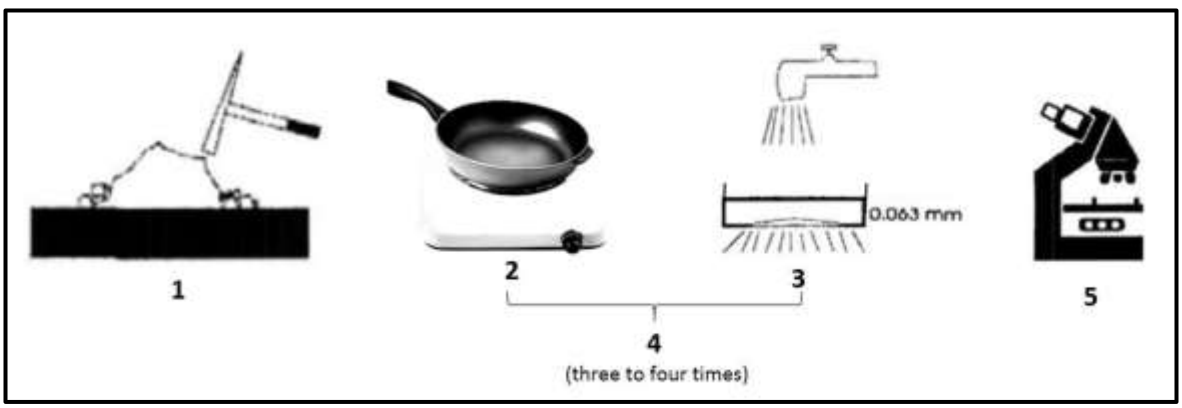


Figure 3.4 Standard processing technique to retrieve microfossil from siliciclastic rock.

3.4 Optimization of the Acetic Acid Method

In addition to using acetic acid on lithified carbonate rocks, in this study I tested the recovery of acid residue obtained by reducing the acid percentage from 80% as proposed by Lirer (2000) to 50%, 60%, or 70%, and the results of using different acid concentrations in terms of fossil recovery, test preservation, specimen cleanliness, and assemblage composition were compared. In this study, stronger concentrations of acid with less reaction time, i.e., five hours for 90% concentration and two hours for 100% concentration was also investigated.

Polished thin sections were studied at the outset of the study to assess the abundance of microfossils present in the samples. A sample rich in microfossils was selected as a potential candidate for acetic acid processing. The sample was subsequently treated with acetic acid using the following steps given below (Figure 3.5):

1) 100g of carbonate sample was broken down into small fragments of about 2 to 5 mm. The small size of fragments is recommended as acid reacts readily with them, and will give better results. However, during crushing of the samples, care should be taken to ensure that the microfossils are not destroyed.
2) Crushed samples are then placed in glass beakers and are properly labeled.
3) Solutions of 100%, 90%, 80%, 70%, 60%, or 50% of acetic acid (CH_3COOH) mixed with 10%, 20%, 30%, 40%, or 50% distilled water respectively were used to disaggregate the samples (the level of the acetic acid / water mixture should be at least 2 cm above the sample level).

4) The submerged samples are left in the solution overnight, for at least 10 to 15 hours, to help the disaggregation process. For the highest concentration of acid, samples were left for 5 hours for 90% and 2 hours for 100% concentrations.
5) The disaggregated samples were wet sieved through stainless steel standard sieves with mesh openings of 1.00 mm, 0.50 mm, and 0.063 mm.
6) The residue from 0.063 mm was dried at low temperature (40-50°C) above a hot plate.
7) The sample residues were transferred to labeled small sample vials. The foraminiferal specimens contained in the residues were sorted using a binocular stereo microscope. The recovery was assessed by weighing the residue, and 300 specimens were picked from each sample. The quality of the sample residue was then assessed by determining the preservation state of the recovered specimens. Both dissolved and partially- or undissolved specimens (specimens that still have matrix attached) were picked and counted.
8) Representative specimens were photographed using a Nikkon-1500 microscope.

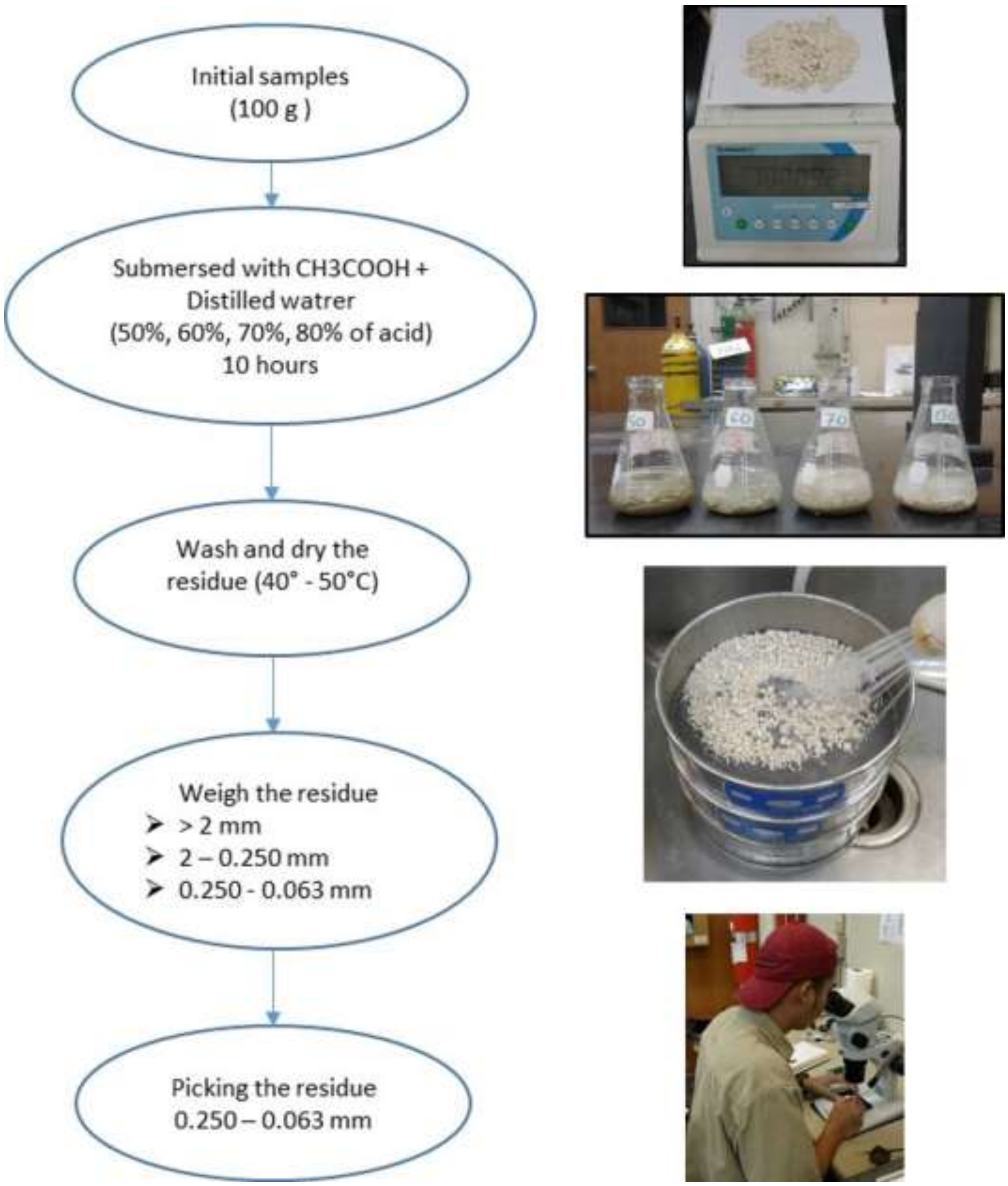


Figure 3.5 Summary flow chart of the main stages in the processing sample using acetic acid.

Recovery of acid residues from the Dam Formation samples and granulometric analysis for different concentrations of acid and processing times show there are slight differences between each concentration and processing times. From an initial sample weight of 100 g, the acetic acid method reduced the weight of the obtained residue by about 18 to 20 g for 50 to 80% concentration and 13 to 14 g for 90% and 100% concentration, with the larger fragments >1 mm accounting for 60 to 65 g (Figure 3.6).

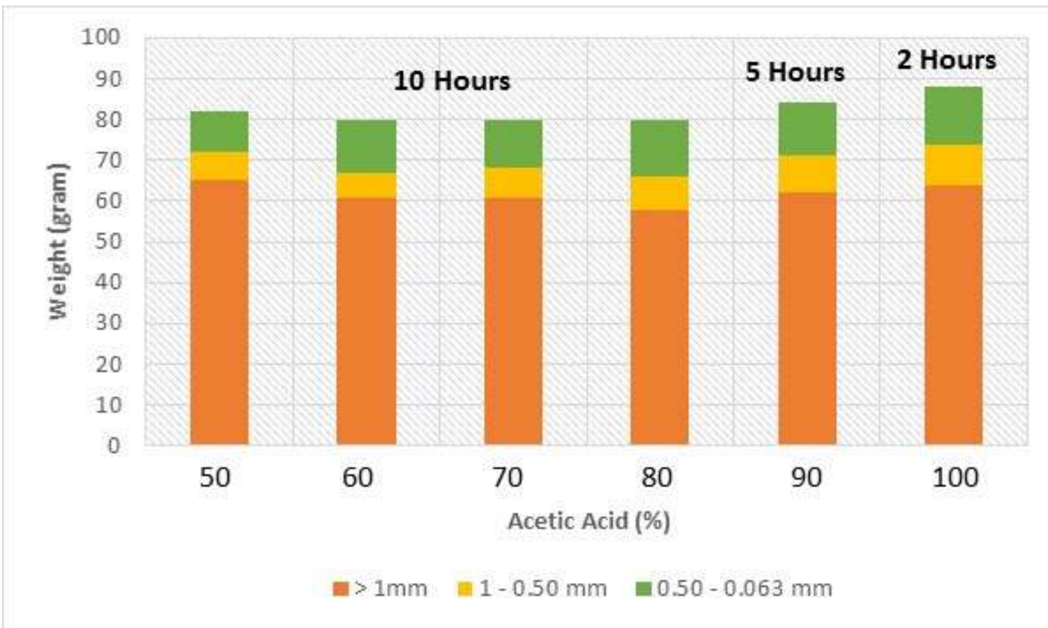


Figure 3.6 Recovery of acid residues from an initial sample size of 100 g, and proportions of three particle size fractions for different concentrations of acid and reaction times.

The small fraction of residues between 0.50 – 0.063 mm were split into 3 g fractions and picked in order to study the preservation, diversity, and the quality of foraminifera from different concentrations of acid.

CHAPTER 4

RESULTS

4.1. Acetic Acid Result

The main differences are observed in the proportions of fully dissolved and partially- or undissolved foraminifera present in each concentration (Figure 4.1). The amount of partially- or undissolved foraminifera decreases from lower concentration (50%) of acid to high concentration of acid (80%) for the same processing time (Figure 4.1). On the other hand, the 90% (5 hours) and 100% (1 hours) shows a high amount of partially- or undissolved foraminifera. This is considered as moderate recovery of foraminifera. Examples of dissolved and partially- or undissolved foraminifera are shown in Figures 4.3 and 4.4. The different species of microfossils recovered from each acid concentration are shown in a pie-chart (Figure 4.2).

Over 300 specimens were picked from residues obtained of various concentrations of acid from this study formation. The main difference for each concentration is the quality and amount of fully dissolved and partially or undissolved foraminifera: either the microfossil is still attached to the matrix, or the matrix is completely removed, and the microfossil has a cleaner surface. In general, the samples showing good recovery especially for 60% to 80% of acid concentrations with 10 hours processing time (Figure 4.1) are categorized as yielding good recovery. The recoveries of 90% and 100% concentrations were classified as fair to moderate. In both of these concentrations, at least 100 specimens out of the 300 specimens counted were found still attached to the rock matrix (Figure 4.4). Nevertheless, even though some of these specimens were found attached to the matrix, they were still recognizable and were identified at least to the generic level.

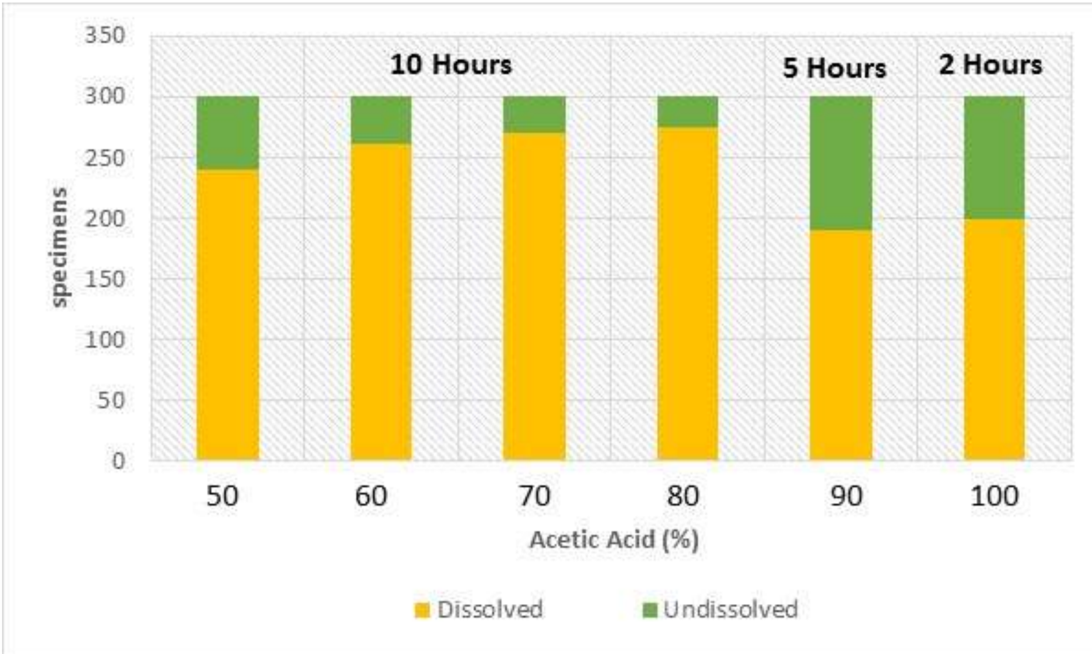


Figure 4.1 Preservation state of foraminifera in a sample of 300 specimens picked from 3 g of the acid residue from the 0.50 – 0.063 mm size fraction. In general, all concentrations show good recovery of foraminifera.

Different concentrations of acetic acid, therefore, can be used for various purposes of the study. If the study requires normal recovery and there is no time constraint, we recommend using a lower concentration of acid, which would be the most environmentally friendly option. However, for better results, acid concentrations can be increased as desired. If quick results are required in an industrial setting to check the fossil content and quantify biogenic proportions such as in the case of drilling monitoring or bio-steering, we would recommend the highest concentrations with a shorter reaction time, as we can still obtain modest microfossil recovery.

The initial particle size of the crushed sample can also influence the results, as acid reacts more quickly with the smaller fragments. Therefore, small sized homogeneous samples are recommended. Care should be taken while crushing the samples to preserve the microfossil content.

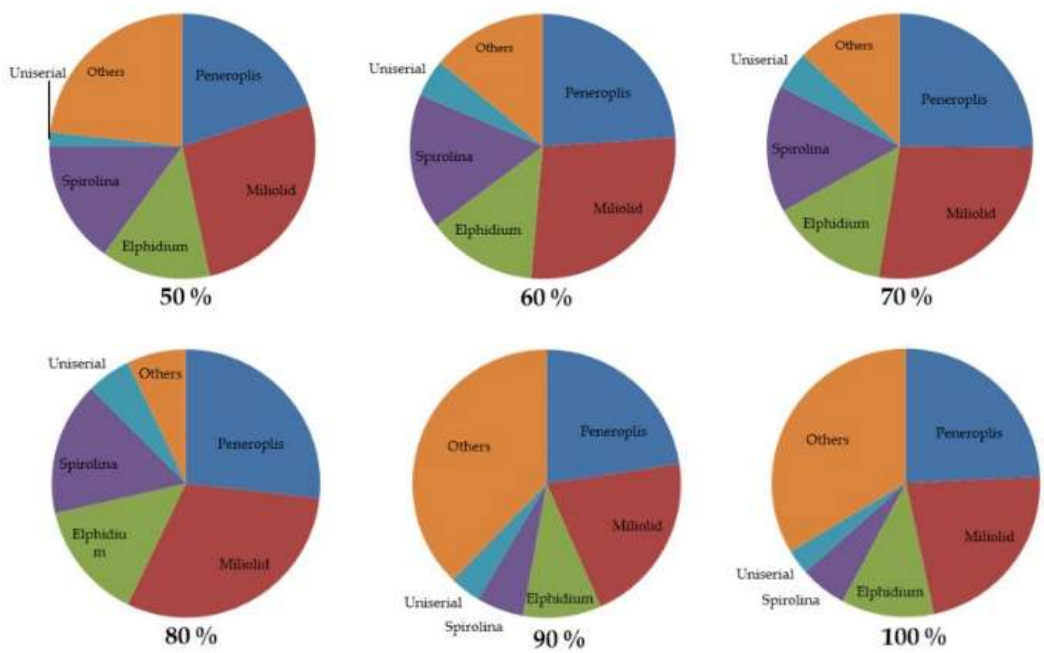


Figure 4.2 Pie-charts showing relative proportions of several species identified from different acid concentrations. "Others" include partially- or undissolved microfossils and unrecognizable microfossils.

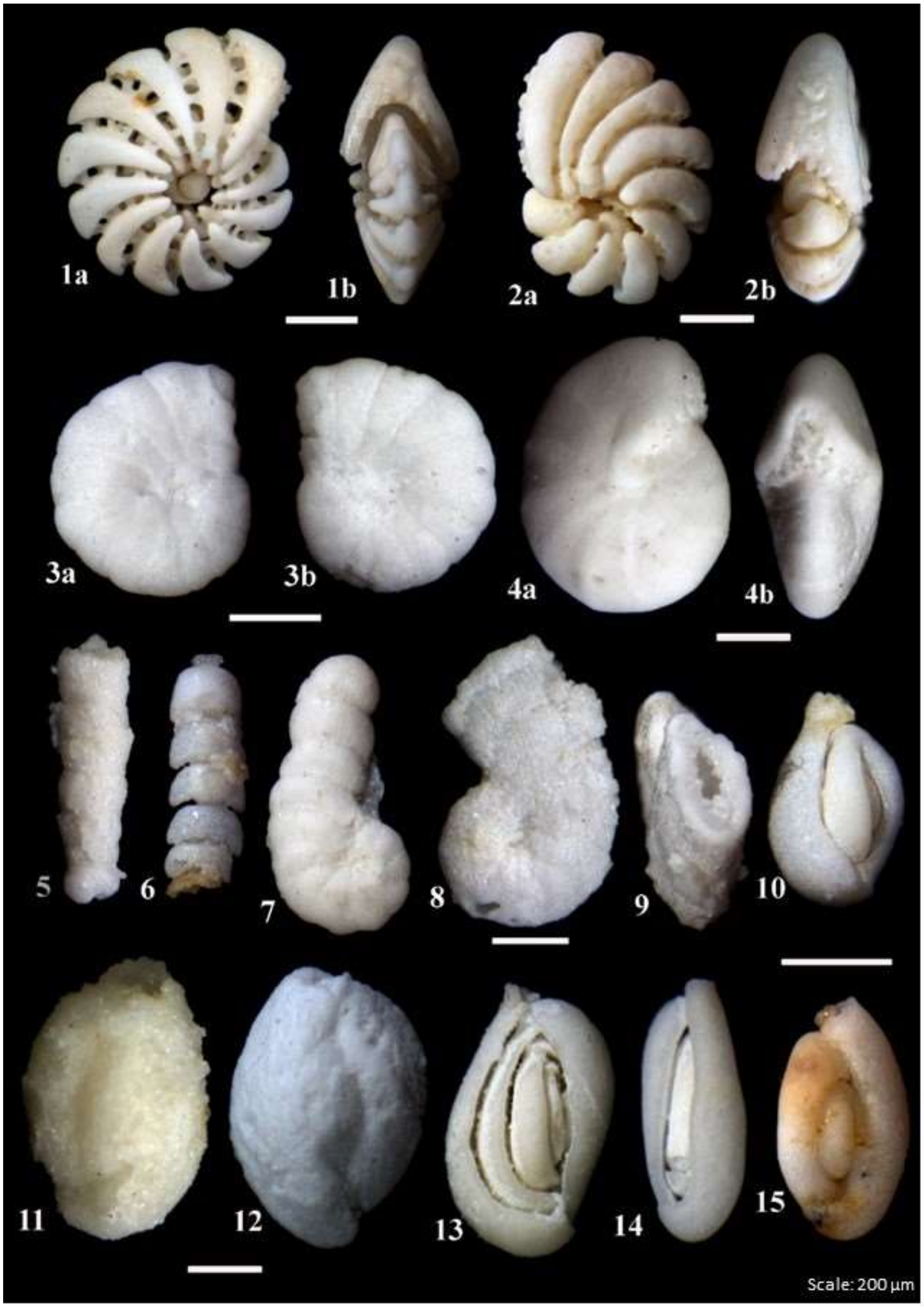


Figure 4.3 Light Microscope image shows an examples of well-preserved foraminifera from each concentration, showing clean wall surfaces

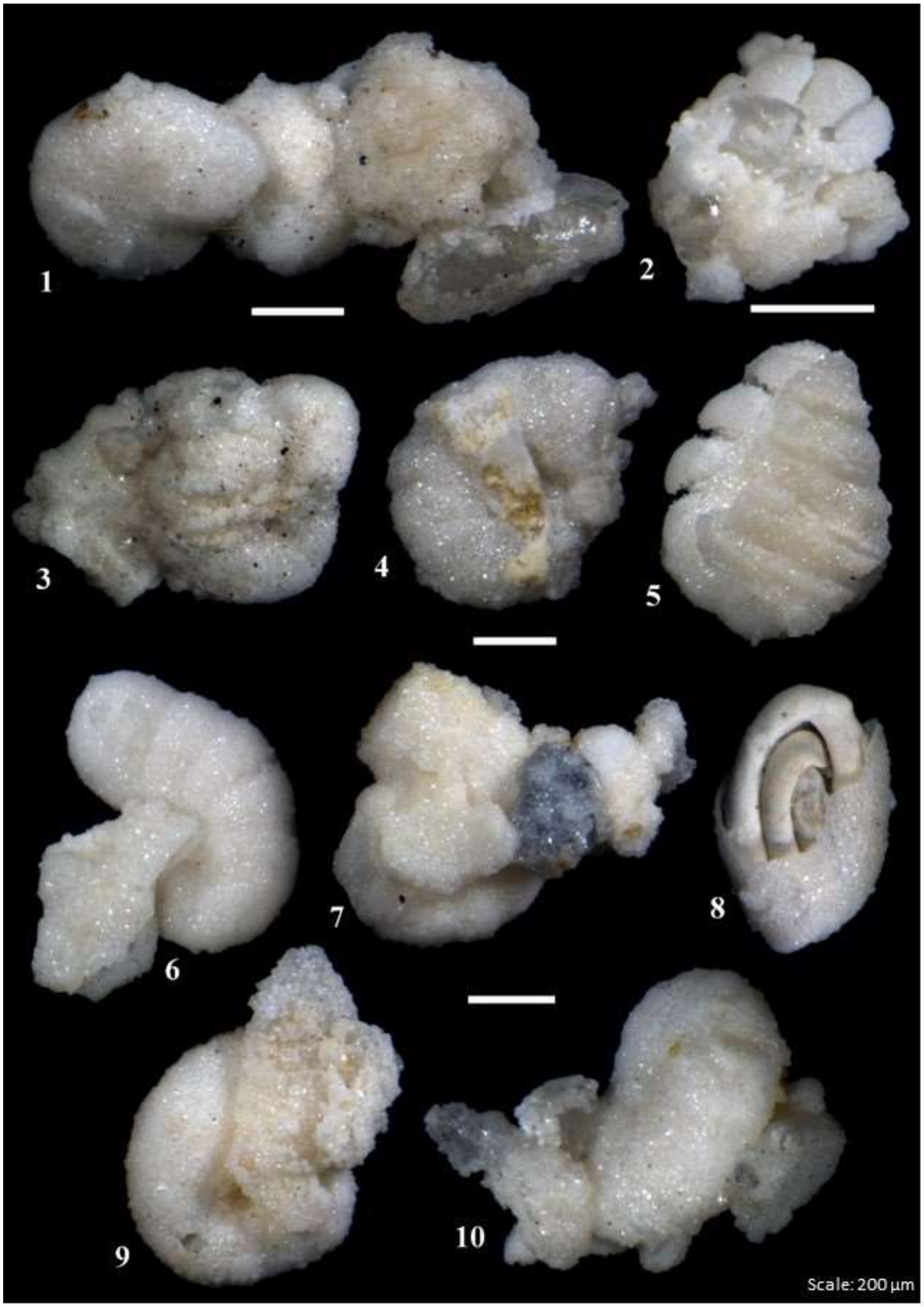


Figure 4.4 Light Microscope image shows an examples of undissolved or partially dissolved foraminifera which are present in each concentration, showing some grains or matrix not completely removed from the foraminifers .

4.2. Lithofacies

The Dam Formation in the Al-Lidam area shows cyclic sedimentation and significant vertical and lateral changes between the studied outcrops (Figure 4.6). Seven lithofacies have been determined from the studied sections. The lithofacies determination based on the field description reported by Bashri (2015) and petrographic thin section description (Figure 4.5). The carbonate lithofacies which account for about 85% are the most abundant lithofacies in this formation. Siliciclastic lithofacies comprise 15% and are mostly located in the western part of the studied section (Figure 4.6).

Mudstone and Evaporites (ME)

This lithofacies found in almost all the studied sections (Figure 4.6) is composed of carbonate mudstone and evaporites. It characterized by mainly massive, thinly laminated locally 0.5-1m thick greenish to red mudstone. It is weathered, showing some desiccation crack. The mineralogy consists of dolomite and anhydrite (Figure 4.5A). No foraminifera are observed in this lithofacies.

Sandstone and Mudstone (SM)

This lithofacies is encountered in the western part of studied section in outcrops 8 and 23, and is absent in outcrops 1, and 2 in the eastern part (Figure 4.6). The lithofacies is composed of quartz grain calcareous sandstone and thinly bedded mudstone (Figure 4.5B). It is characterized by yellow, reddish, silty to fine grains, the presence of trace fossils (Rhizoliths), wavy bedding, mud drapes, tidal bundles, climbing ripples, and a thickness about 3.5 m. No foraminifera were found in this lithofacies.

Stromatolitic Limestone (SL)

This lithofacies is observed in all studied outcrops with different thickness. The thickness ranges from 0.20 to 0.50 m. Morphologically, three types of stromatolites were described from this formation (Nichols, 2009): laterally linked hemispheroid (LLH), discrete spheroids (SS), discrete vertical spheroids (SH), and combination forms (Figure 4.5C). The stromatolites are normally found capping the heterolithic beds of both the carbonate and siliciclastic facies, and are also found within the trough cross-bedded oolitic grainstone layers in the upper part of the section such as in outcrop 1, and 2 (Figure 4.6).

Skeletal Oolitic Grainstone (SOG)

This lithofacies is found only in two outcrops, outcrops 23, and 2 (Figure 4.6). It consists of yellow to white color, medium to coarse grained (grainstone). The lithofacies is predominantly characterized by well-sorted ooids, skeletal fragments (benthic foraminifera, bivalve, gastropod), and quartz grains (Figure 4.5 E, F). The thickness of this lithofacies ranges from 10 cm to 60 cm. The sedimentary structure consists of herringbone cross bedding, trough cross bedding, and planar cross bedding. The foraminifera are rare, only represented by miliolids, *Elphidium*, and *Peneroplis*.

Skeletal Peloidal – Oolitic Grainstone (SPOG)

This lithofacies is mostly found in the lower parts of outcrops 8, and 23 (Figure 4.6). It has a creamy to white color with an average thickness of 40 cm, and is internally laminated. Petrographic thin sections shows a grainstone texture which is composed of peloids, micritized ooid, and skeletal grains (foraminifera and bivalve) (Figure 4.5F). The foraminiferal assemblage is characterized by abundant *Peneroplis*, and *Elphidium*, followed by *Quinqueloculina*, *Triloculina*, *Coscinospira*, *Cibicides*, *Discorbinella*, and *Cornuspira*. (Figure 4.). Gastropods and bivalves also occur as a minor constituent.

Skeletal Packstone – Grainstone (SPG)

This lithofacies with average thickness 40 cm is well developed in all studied outcrops (Figure 4.6). It is yellow to brown, moderately sorted, medium to very coarse grained, containing skeletal fragments, fine to medium peloids, and angular to subrounded quartz grain (Figure 4.5G). The foraminiferal assemblage is characterized by an abundance of miliolids (*Quinqueloculina*, and *Triloculina*), followed by *Elphidium*, *Peneroplis*, *Coscinospira*, *Operculina*, *Cornuspira*, and *Cibicides*. Reworked larger foraminifera are also found in this lithofacies (Figure 4.5F). The occurrences of reworked larger foraminifera indicate the likely presence of a patch reef adjacent to the study area.

Quartz Skeletal Wackstone – Packstone (QSWP)

This lithofacies is found in all the studied outcrops and is one of the dominant lithofacies (Figure 4.6). The thickness ranges from 1 to 3.5 m. The lithofacies is characterized by massive, white to creamy color wackstone to packstone fabric with well-rounded muddy intraformational pebbles (3 – 5 cm). Thin sections show wackstone to packstone texture (Figure 4.5D), dominated by fine quartz grains, and few skeletal grains (foraminifera and bivalves). The foraminiferal are rare, represented by three to five specimens of *Elphidium*, miliolids, a nodosariid, and *Textularia*.

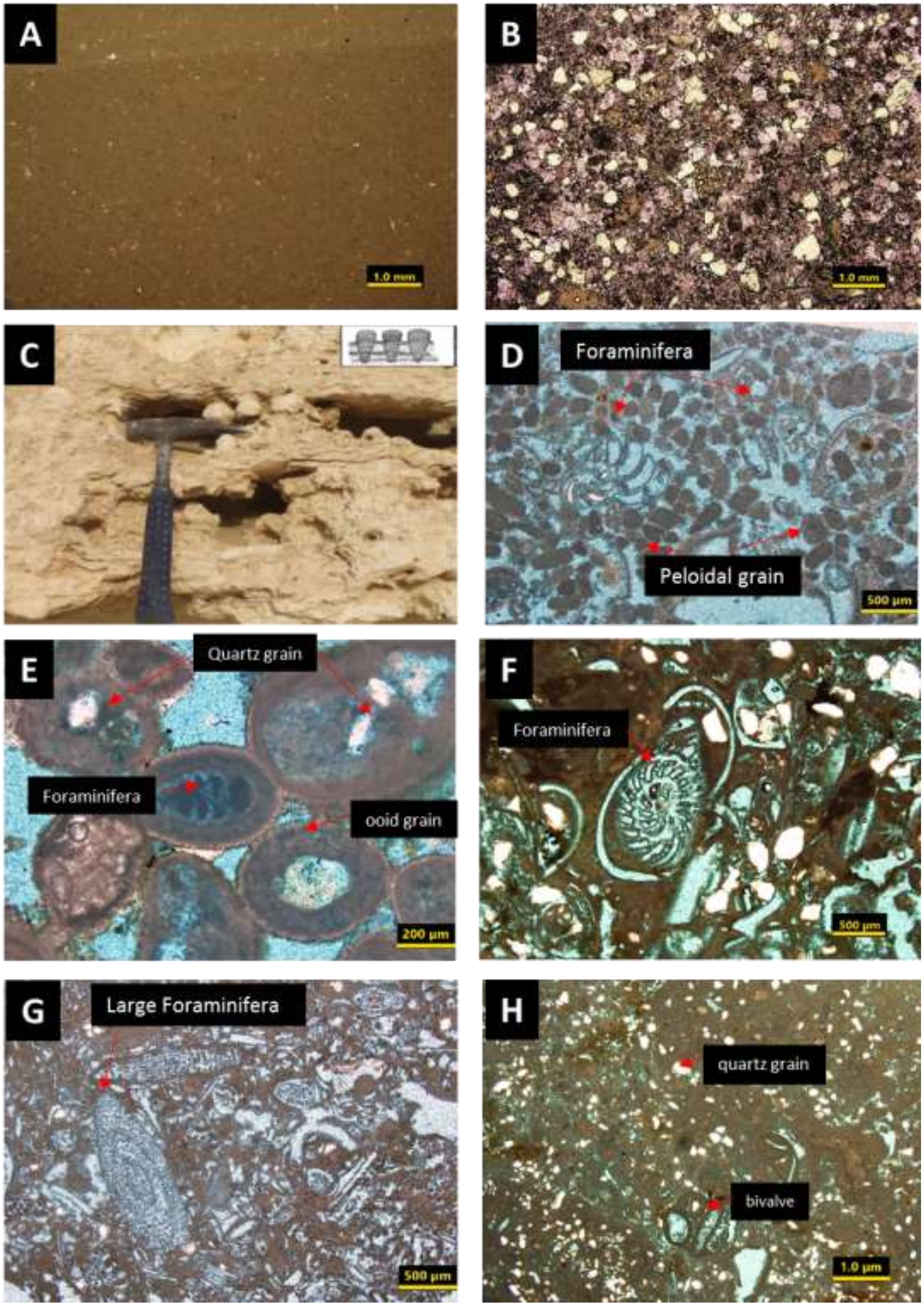


Figure 4.5 Lithofacies representative of the Dam Formation in the Al Lidam area. (A) Mudstone and Evaporites. (B) Sandstone. (C) Stromatolites (Bashri, 2015). (D) Skeletal Peloidal Grainstone (E) Skeletal Oolitic Grainstone. (F, G) Skeletal Packstone – Grainstone with reworked larger foraminifera (H) Quartz Skeletal Wackstone – Packstone.

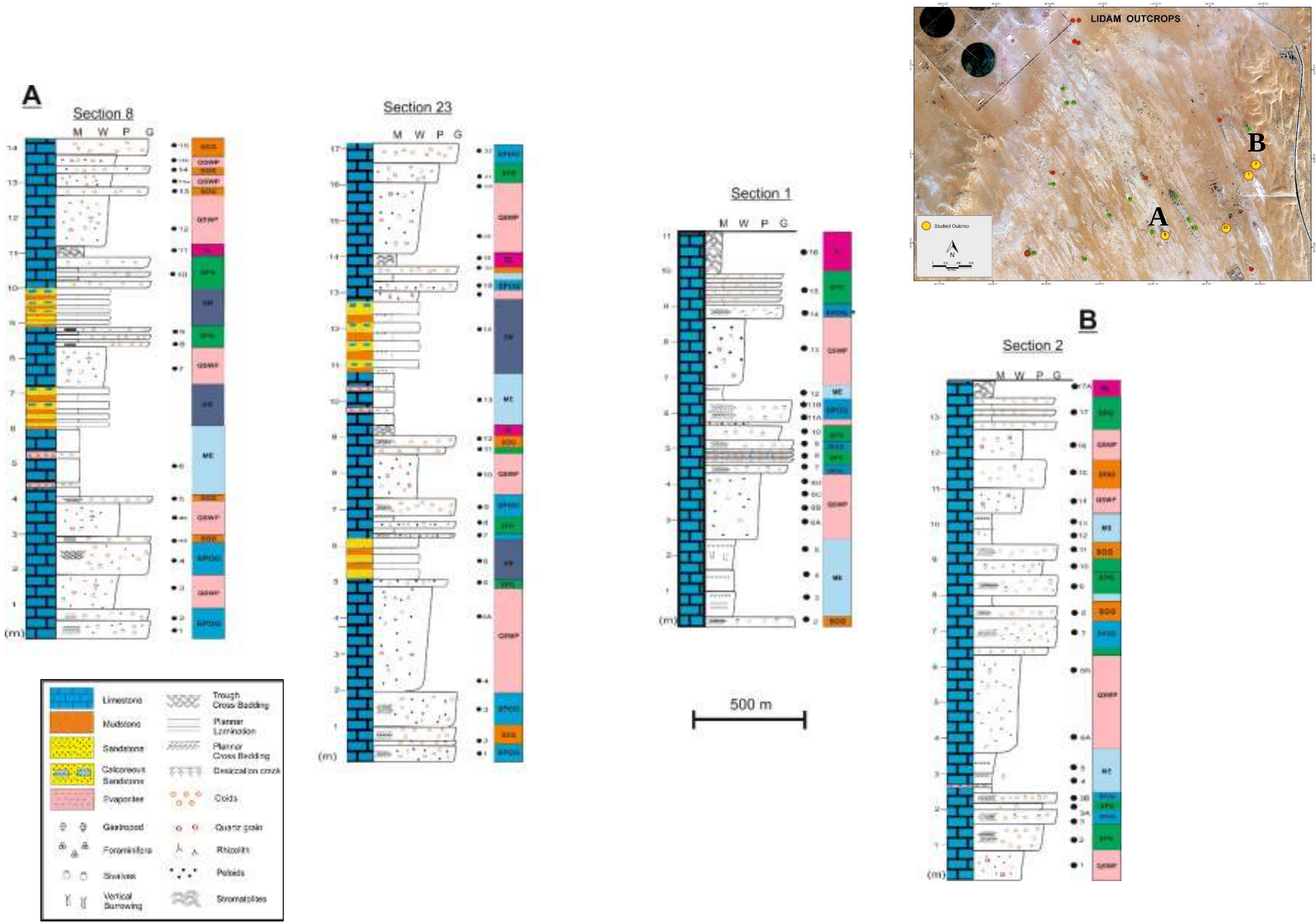


Figure 4.6 Vertical and lateral distribution of lithofacies in the studied outcrop

4.3. Foraminiferal Morphogroups

The main objective of determining morphotypes and morphogroups in this study is to attempt to reveal the paleoenvironmental changes reflected by the foraminiferal assemblages for each lithofacies. The main idea of using morphotypes and morphogroups was originally derived from the agglutinated and calcareous foraminiferal morphogroups established by Corliss and Chen (1988), Corliss and Fois (1990), Nagy (1992), Nagy *et al*. (1995), Van den Akker *et al*. (2000), Cetean (2009), and Setoyama (2012). Kender *et al.* (2008) applied morphogroup analysis to the Miocene benthic foraminiferal assemblages from the Congo fan, offshore Angola. Although the genera present in the Dam Formation are different, we can still use the main idea from the previous morphogroup studies to construct a morphogroup classification for the Miocene of Saudi Arabia.

Murray (2006) defined morphogroups/morphotypes as a group of forms having similar test morphologies rather than taxonomic similarity. Corliss and Chen (1988) established morphotypes as groups of foraminiferal species by the test shape. The idea of combining foraminiferal taxa into morphotypes based on their general morphology rests on the assumption that there is a relationship between “form” and “function” of the foraminiferal test (Nagy *et al*., 1995).

In this study, four morphogroups were determined and are designated alphabetically from A to D (Figure 4.1). Each of these groups, A, B, C, and D are further subdivided into four, two, three, and two morphotypes respectively. The combination of morphotypes into morphogroup categories is mainly based on the test morphology including chamber arrangement, and general outline, life habitat either living on the surface of the sediments or within the sediments (epifaunal or infaunal) (Figure 4.7). An example of each morphotype is summarized in Table 4.1 and Figure 4.9.

Morphogroup A is comprised of species with planispiral chamber arrangement, adapted to epifaunal to shallow infaunal life habitat. Four morphotypes have been differentiated within this morphogroup based on their test forms;

(A1) Biconvex, rounded, globular, involute, and planispiral genera belonging to *Elphidium*, and *Porosononion* (Pl. 1 fig.1) Live benthic foraminifera studies by Kitazato (1981, 1988), Sturrock and Murray (1981), Corliss and Chen (1988) indicated that *Elphidium* has an epifaunal to shallow infaunal life habitat.

(A2) This morphotype is characterized by flattened, depressed form, and planispiral test (Pl. 1 fig.2). This morphotype represents by two genera; *Peneroplis* and *Operculina*. Kitazato (1981, 1988), Sturrock and Murray (1981) reported that living specimens of *Peneroplis* have an epifaunal to epiphytal life habitat.

(A3) Uncoiling planispiral test shape (*Coscinospira* and *Spirolina*.) (Pl. 7 figs.1 - 6). The life habitat of these genera is similar to *Peneroplis,* which is epifaunal in habitat.

(A4) Tubular form, planispiral chamber arrangement (Pl. 4 fig. 6), with living on the surface of the sediments (epifaunal) and represented by *Cornuspira*.

Morphogroup B includes species with chamber arrangement trochospiral, biconvex, planoconvex, and epifaunal in habitat. *Cibicides* and *Discorbinella* are reported as having an epifaunal life style by Kitazato (1981, 1988), Sturrock and Murray (1981), Corliss and Chen (1990). Two morphotypes are differentiated within this group;

(B1) Biconvex, trochospiral tests (Pl. 5 figs. 1, 3). This type is represented by three genera; *Cibicides*, *Ammonia,* and *Rotalia*.

(B2) Planoconvex test form, chamber arrangement trochospiral, concave on the umbilical side (Pl. 5 figs. 6-7), epifaunal life habitat. One genus is present in this morphotype, *Discorbinella*.

Morphogroup C comprises all the miliolid genera (Pl. 8, 9, 10). Corliss and Chen (1988), Corliss and Fois (1990), and Murray (2006) reported that the living habitat of miliolids is epifaunal. Three different morphotypes are placed in this group;

(C1) Miliolid-Quinqueloculina. The genera included here are *Quinqueloculina*, *Triloculina*, and *Sigmoilinita*.

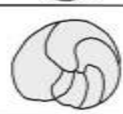
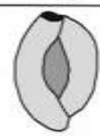
(C2) Miliolid-Pyrgo. Represented by *Pyrgo,* and related forms (Pl. 10 fig. 9).

(C3) Miliolid-Borelis (Pl. 11 fig. 6). *Borelis melo melo* is the representative species of this morphotype.

Morphogroup D is comprised of two morphotypes; (D1) this category is represented by a uniserial chamber arrangement, and cylindrical test shape (Pl. 6 fig. 1-6). The organisms are interpreted as infaunal, either embedded in soft sediments or cemented to the sea floor (Jones and Charnock, 1985). Among which *Stilostomella* and the nodosariid group are representative taxa.

(D2) This morphotype is made up by elongated biserial agglutinated forms (Pl. 11 figs. 9-11) with an infaunal life habitat, and is represented by *Textularia*. Studies by Kitazato (1981, 1988), and Sturrock and Murray (1981) indicate that the genus *Textularia* has an infaunal life habitat.

Table 4.1 Calcareous benthic foraminiferal morphogroups and morphotypes differentiated according to shell morphology.

Morpho-groups	Morphotype		Test Form	Life Position	Main Genera	Lithofacies
A	A1		Biconvex Planispiral	Epifaunal to Shallow Infaunal	*Elphidium*	QSWP SOG SPOG SPG
	A2		Flattened depressed Planispiral	Epifaunal	*Peneroplis* *Operculina*	SOG SPOG SPG
	A3		Uncoiling Planispiral	Epifaunal	*Spirolina* *Coscinospira*	SPOG SPG
	A4		Tubular Planispiral	Epifaunal	*Cornuspira*	SPG
B	B1		Biconvex Trochospiral	Epifaunal	*Cibicides* *Rotalia* *Ammonia*	SPOG SPG
	B2		Planoconvex Trochospiral	Epifaunal	*Discorbinella*	
C	C1		Miliolid-Quinquecloculina Triloculina	Epifaunal to Shallow Infaunal	*Quinqueloculina* *Triloculina* *Sigmoilinita*	QSWP SOG SPOG SPG
	C2		Miliolid-Pygro	Epifaunal to Shallow Infaunal	*Pyrgo*	SPG
	C3		Miliolid-Fusiform to Spherical	Epifaunal	*Borelis*	QSWP
D	D1		Cylindrical Uniserial	Erect Epifaunal to shallow Infaunal	*Stilostomella* *Nodosariid*	QSWP
	D2		Agglutinated Biserial	Infaunal	*Textularia*	

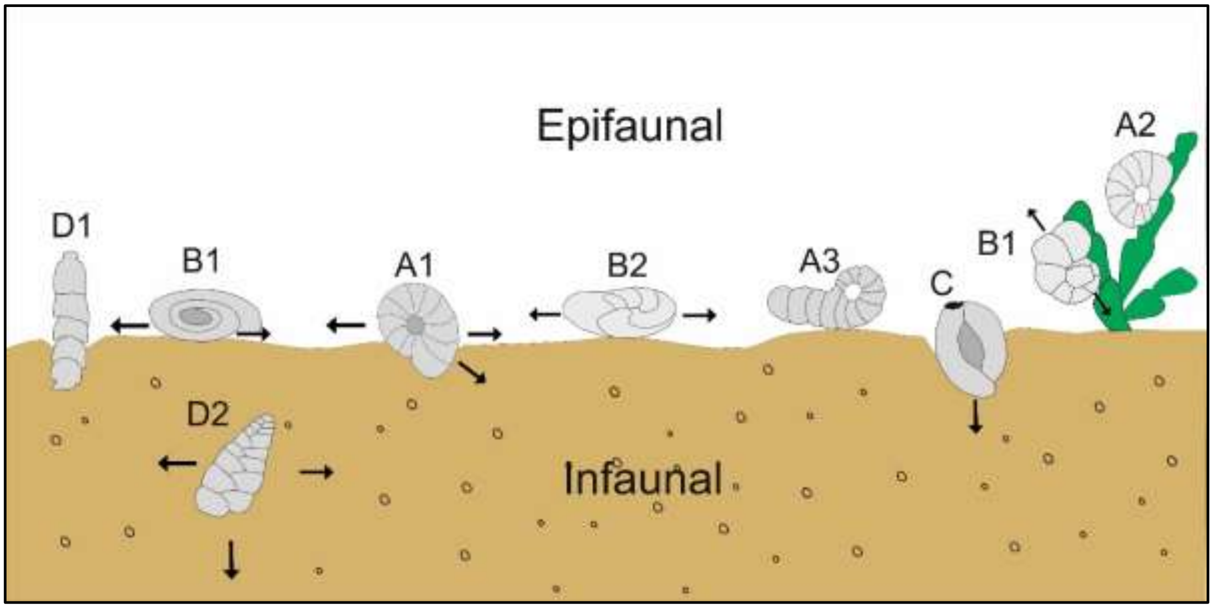


Figure 4.7 Calcareous benthic foraminiferal morphogroup life habit position. Living above the substrates (epifaunal) and living within the substrates (infaunal).

In general, the total assemblages are dominated by the epifaunal taxa (Figure 4.3). The dominance of epifaunal assemblages is a typical of a shallow marine environment (Corliss and Fois 1990). Three main morphotypes which dominate the studied formation are comprised of: the Miliolid-Quinqueloculina (C1), flattened depressed planispiral (A2), and biconvex planispiral (A1), which represent 40%, 26%, and 19% respectively (Figure 4.10). The other eight morphotypes (A3, A4, B1, B2, C2, C3, D1, and D2) remain minor constituents of the assemblages each amounting between 1% and 8%.

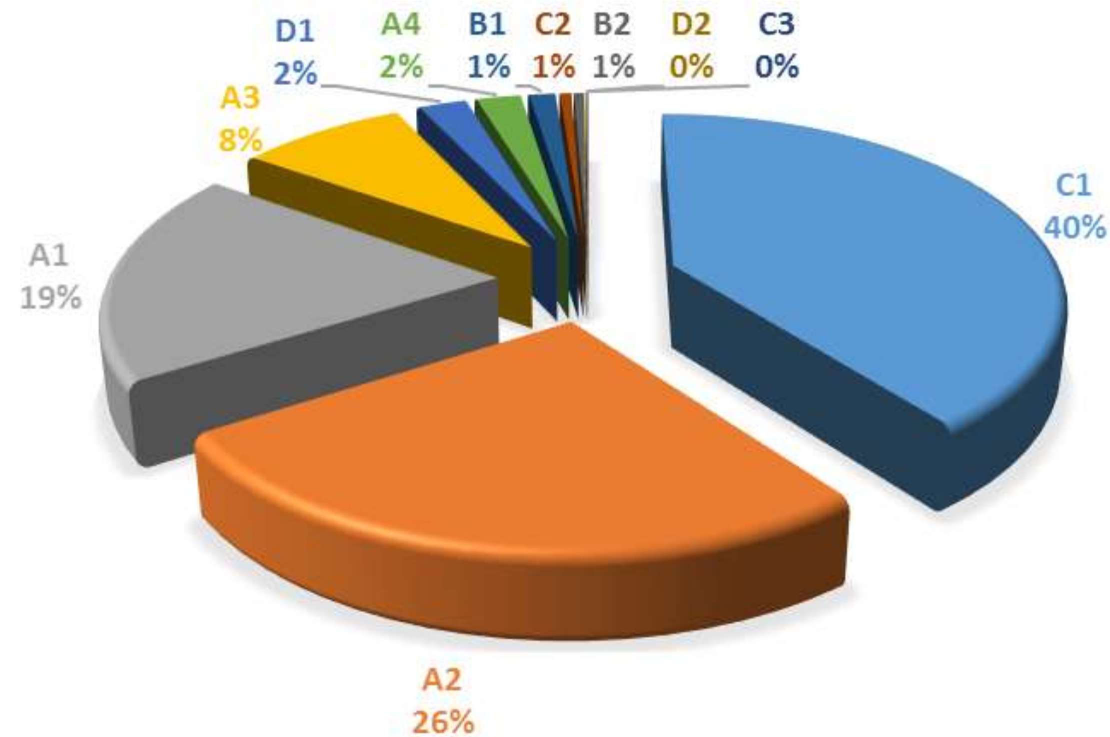


Figure 4.8 Percentage of the total assemblage for each Morphotype which dominated by Miliolid-Quinqueloculina (C1), flattened depressed planispiral (A2), and biconvex planispiral (A1)

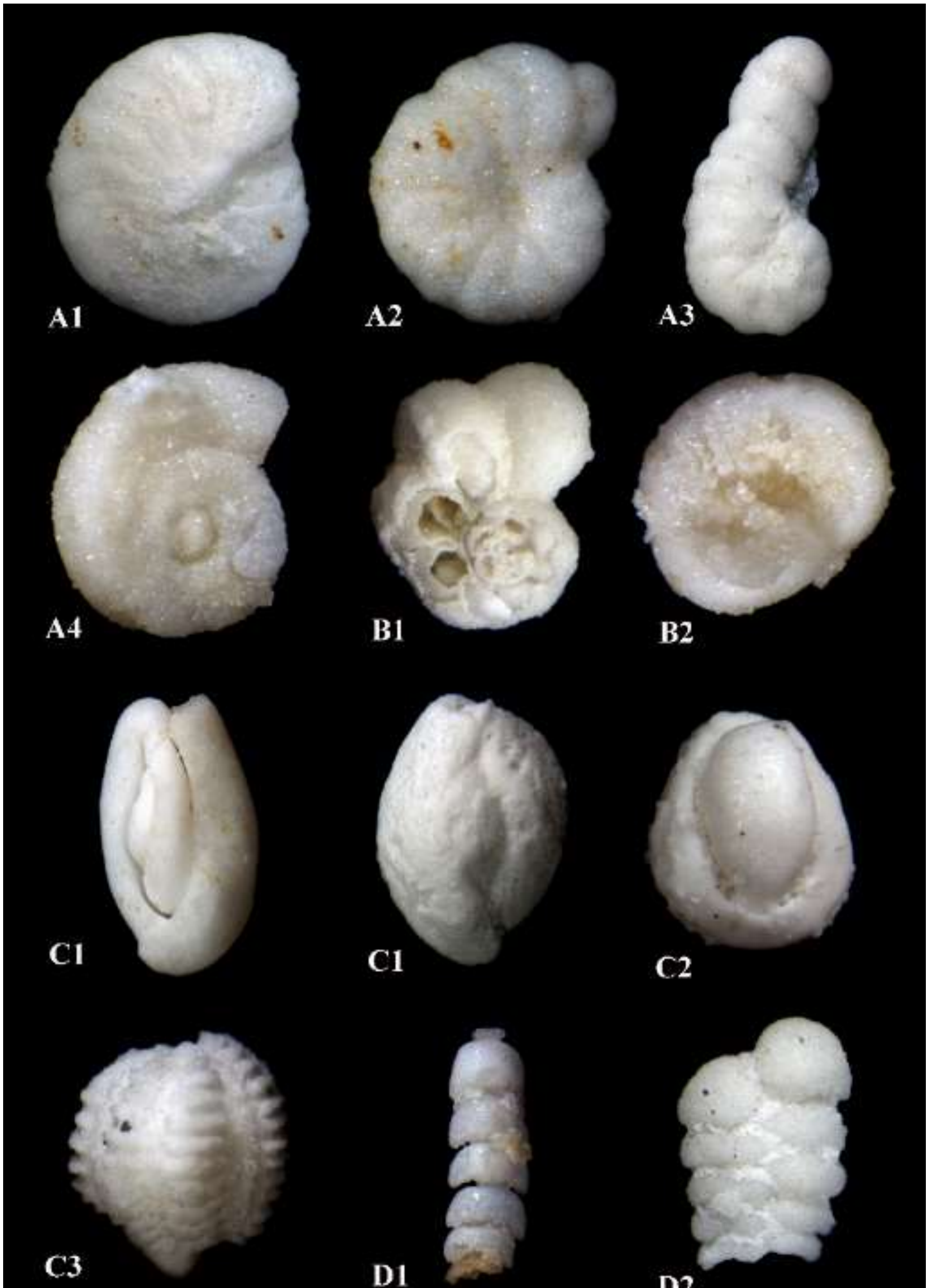


Figure 4.9 Light Microscope image shows example of morphotypes from the studied formation. (A1) Biconvex Planispiral, (A2) Flattened depressed, (A3) Uncoiling Planispiral, (A4) Tubular Planispiral, (B1) Biconvex Trochospiral, (B2) Planoconvex Trochospiral, (C1) Miliolid-Quinqueloculina, (C2) Miliolid-Pyrgo, (D1) Uniserial, and (D2) Agglutinated Biserial.

4.4. Foraminiferal Identification

The results of foraminiferal analysis from the acetic acid treated samples (Pl. 1-11) and thin sections (Pl. 12-17) from the Dam Formation in the Al-Lidam area identified 46 species of benthic foraminifera that belong to 24 genera, 16 families, and three suborders (Table 4.2). The samples were dominated only by benthic foraminiferal genera whereas the planktonic foraminifera is completely absent.

Due to the preservation status, most of the microfossil specimens in the samples occur as molds with their outer walls dissolved during diagenesis (Pl. 1-11). Therefore it is hard to identify some genera to the exact species level. Hence, the identification carried out in this study is mostly limited to the generic level.

The taxonomy used in this study is based on the Loeblich and Tappan (1994) monograph and previous studies on the Miocene from the Indo-Pacific, Paratethys, and Mediteranian regions by Drooger *et al.* (1955), Bhatia and Mohan (1959), Mohan and Bhatt (1966), Popescu (1979), Cicha (1998), Al-Saad and Ibrahim (2002), Reuter *et al*. (2007), Gonera (2012), and Hughes (2014).

The assemblages recovered from the Dam Formation in the Al-Lidam area are characterized by the dominance of Miliolina (*Quinqueloculina, Peneroplis*, *Triloculina*, *Cornuspira, Sigmoilinita*, *Coscinospira, Spirolina, Pyrgo, Borelis)* which prevail over the Rotaliina (*Elphidium, Ammonia*, *Cibicides, Discorbinella*) and Textularina (Figure 4.5). The foraminifera encountered in this study are listed in Table 4.2 and the distribution of the identified specimens is illustrated in Plates 1 – 17.

Table 4.2 Miocene foraminifera of the Dam Formation in Al-Lidam area.

Suborder*	Family	Genus	Wall Structure
Textularina	Textulariidae	*Textularia*	agglutinated
Miliolina	Alveolinidae	*Borelis*	calcareous porcellaneous
	Cornuspiridae	*Cornuspira*	
	Hauerinidae	*Pseudotriloculina*	
		Pyrgo	
		Quinqueloculina	
		Triloculina	
		Sigmoilinita	
	Peneroplidae	*Coscinospira*	
		Peneroplis	
		Spirolina	
Rotaliina	Amphisteginidae	*Amphistegina*	calcareous hyaline
	Cibicididae	*Cibicides*	
		Cibicidoides	
	Discorbidae	*Discorbis*	
	Discorbinellidae	*Discorbinella*	
	Elphidiidae	*Cribroelphidium*	
		Elphidium	
	Nonionidae	*Pullenia*	
	Nummulitidae	*Operculina*	
	Planorbulinidae	*Planorbulina*	
	Rotaliidae	*Ammonia*	
		Rotalia	
	Stilostomellidae	*Stilostomella*	

*- the systematic concept according to Loeblich and Tappan (1994).

Figure 4.10 shows the percentages of the dominant sub-orders and genera within the studied formation. In total, the foraminiferal assemblage is composed of three main suborders of which 75% are accounted by calcareous porcellaneous (Miliolina), 24% are calcareous hyaline (Rotaliina), and 1% has an agglutinated wall (Figure 4.10 A). The most abundant genera from the Miliolina sub-order (Figure 4.10C) includes *Quinqueloculina* (27%), *Peneroplis* (22%), *Triloculina* (13%), *Coscinospira* (9%), and *Sigmoilinita* (5%). The sub-order Rotaliina, is dominated by *Elphidium* (17%), *Ammonia* (5%), *Cibicides* and *Discorbinella* (1%) (Figure 4.10D).

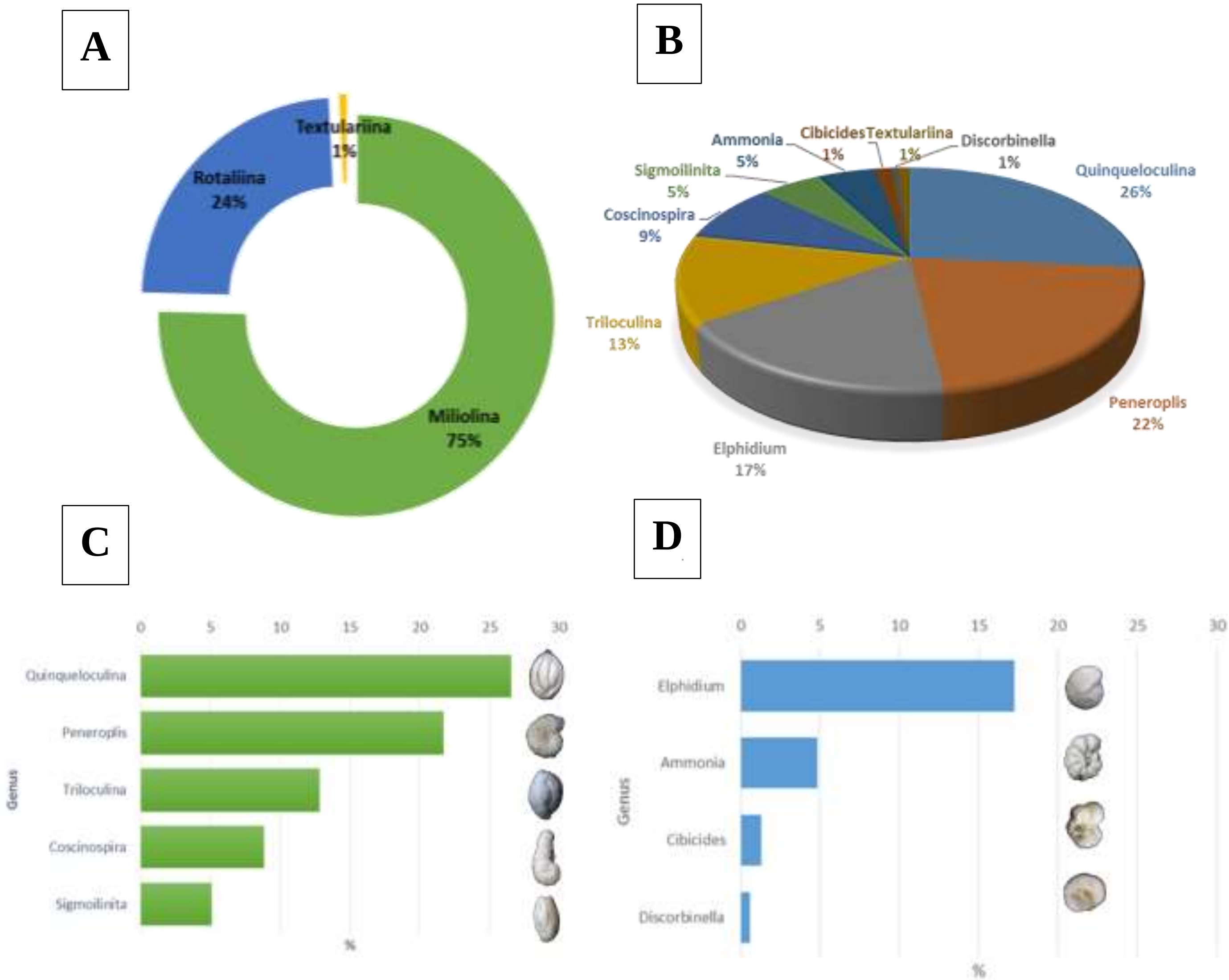


Figure 4.10 Quantitative representation of foraminiferal assemblages in the Dam Formation (A) Percentage of the suborders, (B) The percentage of most abundant genera, (C) most abundant genera of Miliolina, (D) most abundant genera of Rotaliina.

4.5. Foraminiferal Assemblages

The total number of specimens and morphotypes were counted and plotted for each stratigraphic section to examine the vertical and lateral variations of the foraminiferal assemblages within the studied sections. Eleven foraminiferal assemblages were recognized in the Dam Formation (Figure 4.14, 4.18, 4.22, 4.26).

The determination of the assemblages was based on the dominance of the main genera and morphotypes from each sedimentary package which changes vertically. The change in the foraminiferal assemblages is considered as reflecting a shift in the environment during the time of deposition. The presences or absence of foraminifera may furthermore reflect a sea - level change and a change from marine setting to a continental setting. In this study, the presence of foraminifera is interpreted to indicate a marine environment whereas their absence reflects a sea - level drop and a change to a continental or tidal flat environment as shown in Figure 4.14, 4.18, 4.22, 4.26.

Three foraminiferal assemblages were described from outcrops 8, 23, 2 respectively and two assemblages were recognized from outcrop 1.

Assemblage 1:

This assemblage located in the lower part of outcrop 8 (Figure 4.14). Seven genera were encountered in this assemblage. The assemblage is dominated by the abundance of *Peneroplis* (44%), *Elphidium* (29%), and *Quinqueloculina* (16%). *Ammonia*, *Triloculina*, *Textularia*, and *Pyrgo* which account for 7%, 4%, and 1% respectively occur as minor constituents of this faunal assemblage (Figure 4.11).

Assemblage 2:

The assemblage is located in the middle of outcrop 8, is represented by 11 genera. This assemblage is dominated by morphotypes A2, and C1 (Figure 4.14). The most commonly occurring genera are *Peneroplis* (26%), *Quinqueloculina* (25%), and *Coscinospira* (16%). Eight other genera account for the remaining 33% of this assemblage (Figure 4.14) including; nodosariids (7%), *Elphidium* (6%), *Triloculina* (6%), *Discorbinella* (4%), *Spirolina* (4%), *Sigmoilinita* (3%), *Ammonia,* and *Cibicidoides* (1%) (Figure 4.12). Other observed microfossils include bivalves, and gastropods.

Assemblage 3:

In general, this assemblage shows low faunal diversity with absolute abundances ranging from present to rare. The assemblage was found in the upper part of outcrop 8 (Figure 4.14). Approximately 100 specimens were counted, and these are represented only by three genera, *Quinqueloculina*, *Elphidium,* and *Peneroplis* (Figure 4.13).

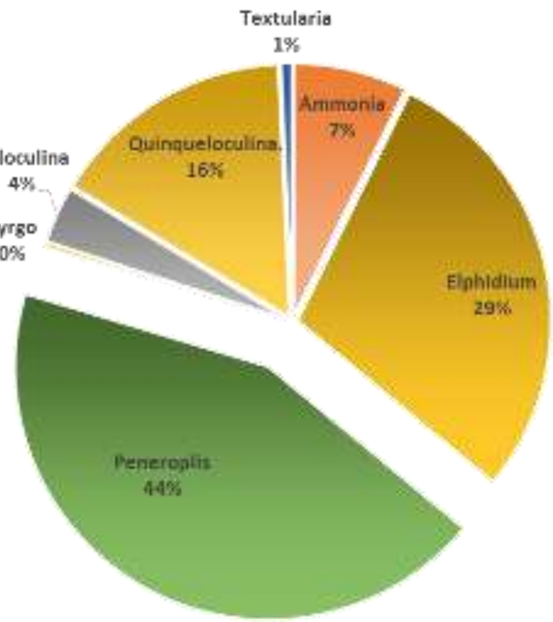


Figure 4.11 The percentage of common genera from Assemblage 1, located in the lower part of section 8.

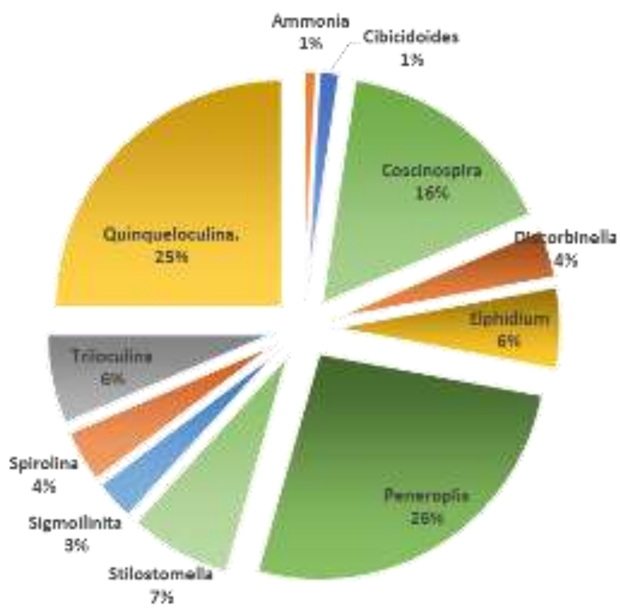


Figure 4.12 The percentage of main genera from Assemblage 2.

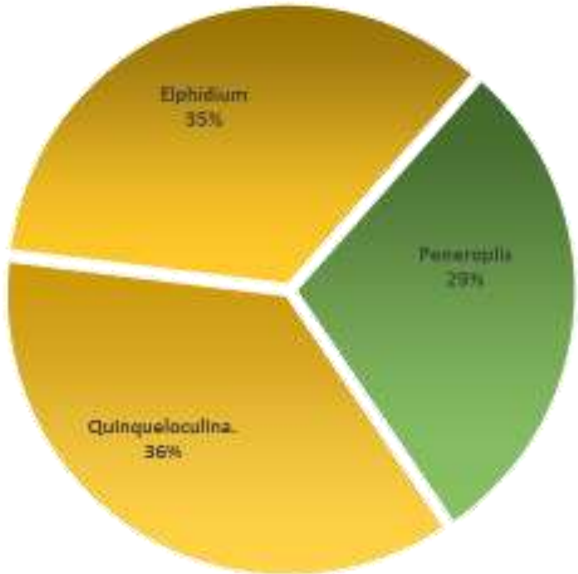


Figure 4.13 The percentage of genera from Assemblage 3.

Section 8

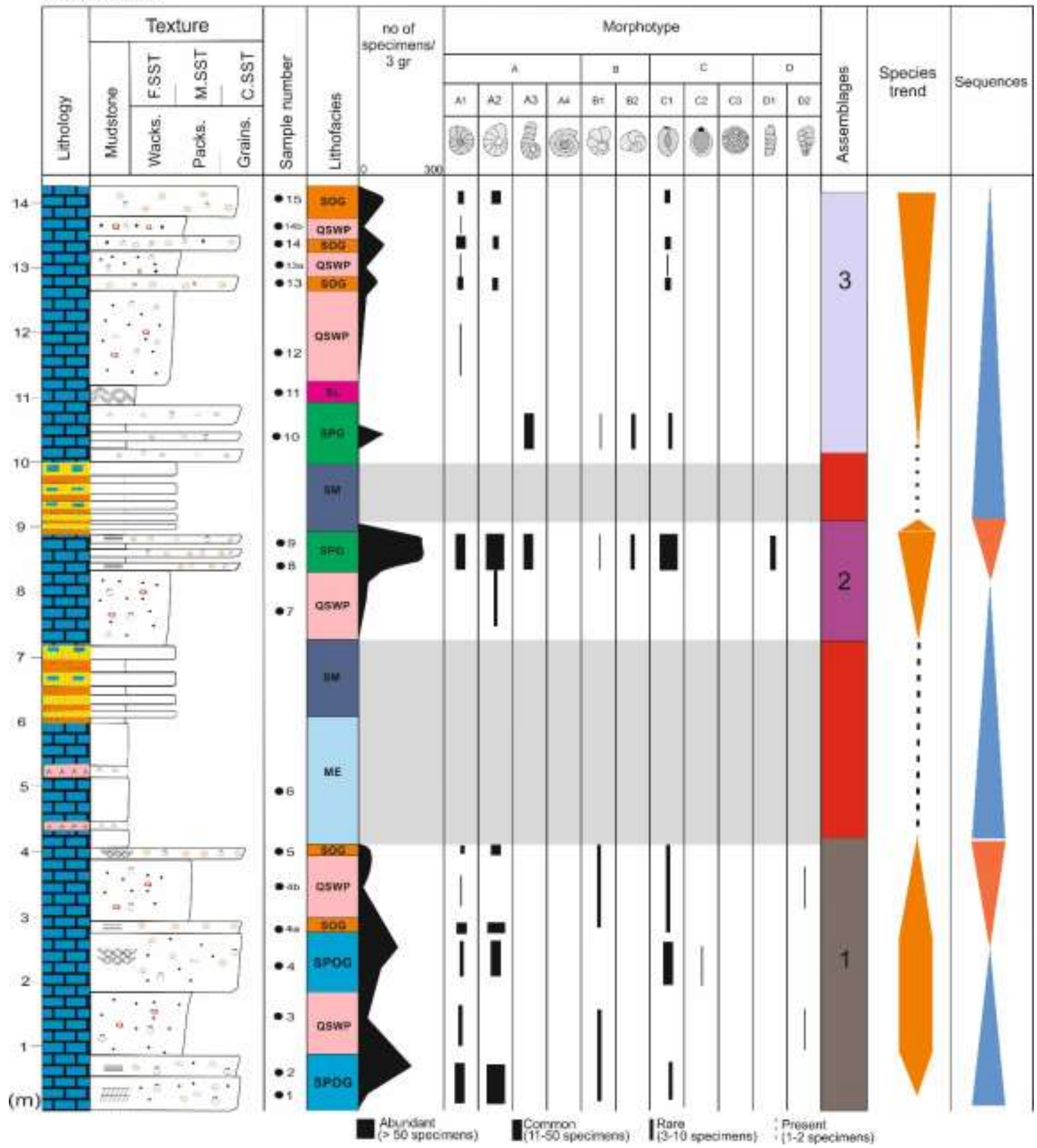


Figure 4.14 Stratigraphic column of section 8, showing the vertical distribution of specimens and morphotypes, with a sequence stratigraphic interpretation.

Assemblage 4:

The identified foraminiferal in this assemblages represented by 10 genera (Figure 4.15). Assemblage 4 which is located in the lower part of section 23 (Figure 4.18). Is composed of a high percentage of *Peneroplis* (38%), followed by *Elphidium* (22%), *Quinqueloculina* (16%), and low percentages of *Coscinospira* (8%), *Stilostomella*, *Cibicides* (5%), *Triloculina*, *Discorbinella* (3%), *Cornuspira* (2%), *Textularia*, and *Borelis melo* (1%). gastropods and bivalves also occur as a minor constituent of this assemblage.

Assemblage 5:

This assemblage is comprised of 100 specimens of foraminifera and is located in the middle of outcrop 23 (Figure 4.18). Eleven genera were identified in this assemblage, characterized by the high percentage of *Quinqueloculina* (34%), *Elphidium* (27%), and *Peneroplis* (13%). The others genera encountered in this assemblage include; *Triloculina*, (9%), *Discorbinella* (7%), *Cornuspira* (6%), *Sigmolinita* (4%), and *Pyrgo* (1%) (Figure 4.16).

Assemblage 6:

This assemblage comprises 300 specimens and is located in the upper part of section 23 (Figure 4.18). Ten genera were identified in this assemblages and characterized by common to abundant morphotypes A2 and C1, followed by the present to common morphotypes A1, A3, A4, B1, and D2 respectively (Figure 4.18). The most commonly occurring genera are *Peneroplis* (30%), *Elphidium* (19%), *Coscinospira* (17%), *Quinqueloculina* (12%), and low percentages of *Triloculina* (4%), *Pullenia* (3%), *Stilostomella*, *Operculina* (2%), *Cornuspira*, and *Cibicides* (1%) (Figure 4.17).

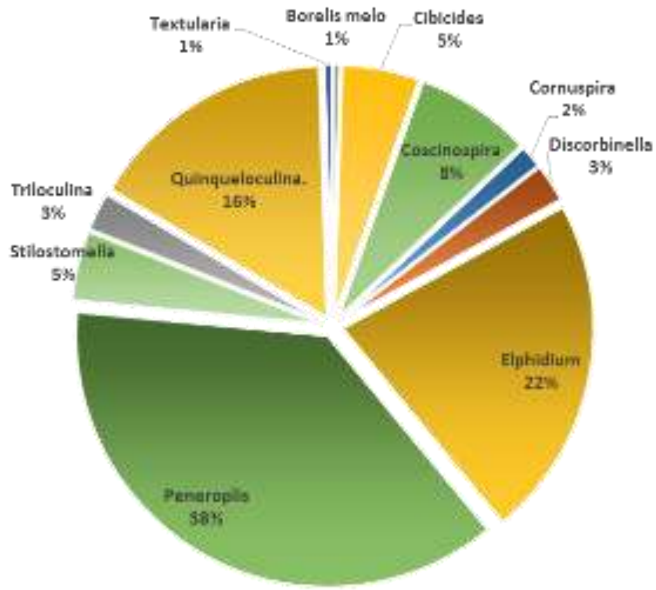


Figure 4.15 The percentage of genera from Assemblage 4.

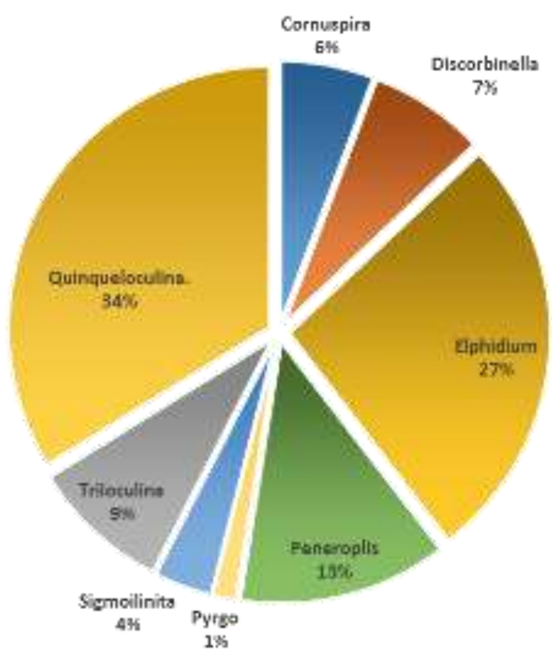


Figure 4.16 The percentage of main genera from Assemblage 5.

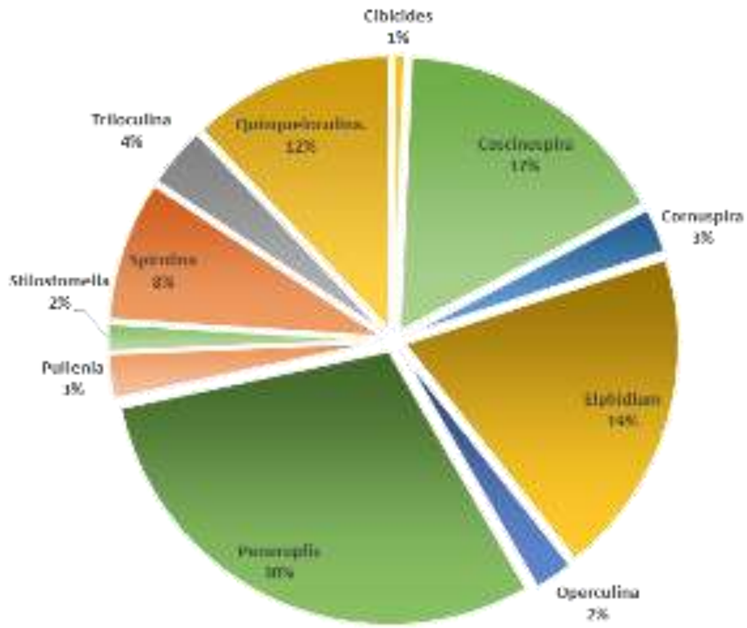


Figure 4.17 The percentage of main genera from Assemblage 6.

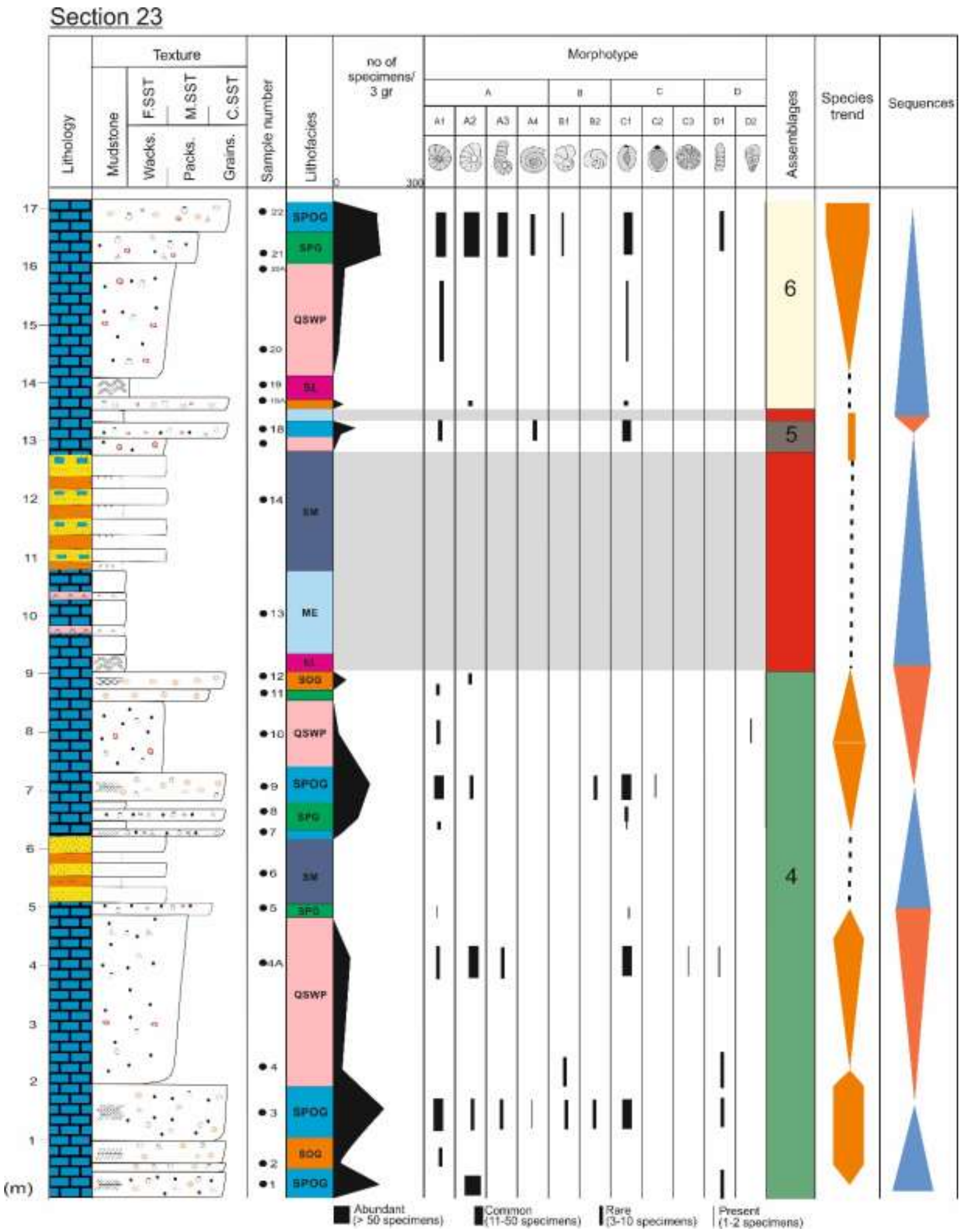


Figure 4.18 Stratigraphic column of section 23, shows vertical distribution of specimens, morphotype, species trends, and sequence stratigraphic interpretation.

Assemblage 7:

This assemblage is characterized by a high diversity of foraminiferal taxa and shows an increase in the percentage of *Quinqueloculina* compared with outcrop 8 and 23. The most characteristic morphotype in this assemblage is C1, followed by A2, and A1 (Figure 4.22). About 650 specimens were counted in this assemblage. The most frequent genera include *Quinqueloculina* (52%), *Peneroplis* (18%), *Elphidium* (11%), *Coscinospira* (7%), *Triloculina* (3%), *Stilostomella* (4%) and *Ammonia* (2%). *Rotalia, Pyrgo, Textularia, Discorbis,* and *Cibicides* each contributes about 1% of the total specimen counts (Figure 4.19). This assemblage is also characterized by the presence of reworked larger foraminifera (Figure 4.22) which are found in sample 10, such as alveolinids (A), lepidocyclinids (B, C), and operculinids (D). All the larger foraminifera indicate a more marine environment and are typical of a reef environment.

Assemblage 8:

This assemblage is located in the upper part of outcrop 1 (Figure 4.21). Eight genera from a total of 120 specimens were identified in this assemblage. The assemblage is dominated by *Peneroplis* (32%), *Quinqueloculina* (20%), *Elphidium* (16%), and *Coscinospira* (16%). Four genera account for 16% of the total abundances in this assemblages. These include *Spirolina* (8%), *Sigmoilinita* (4%), *Triloculina* (2%), and *Ammonia* (1%) (Figure 4.21). In Seven morphotypes were identified in this assemblage, abundant to common morphotype C1 and A2, rare to common morphotype A1, A3, B1, B2, and D1 (Figure 4.19). Other observed microfossils include bivalves, ostracods, and gastropods.

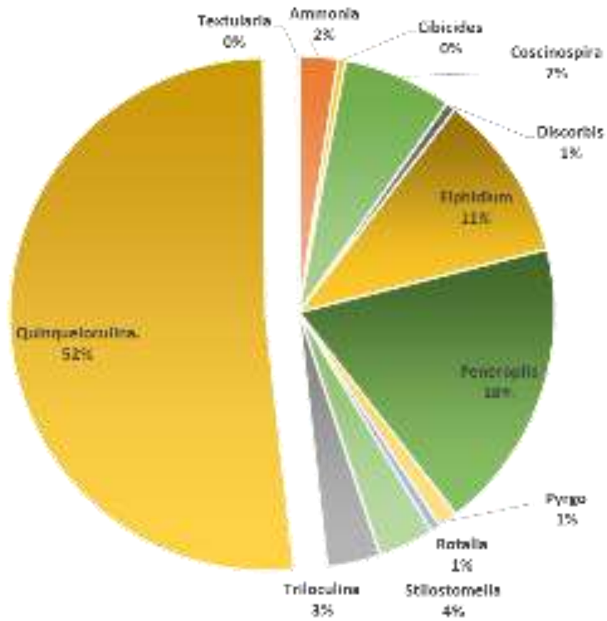


Figure 4.19 The percentage of main genera from Assemblage 7. Characterized by the abundance of *Quinqueloculina*.

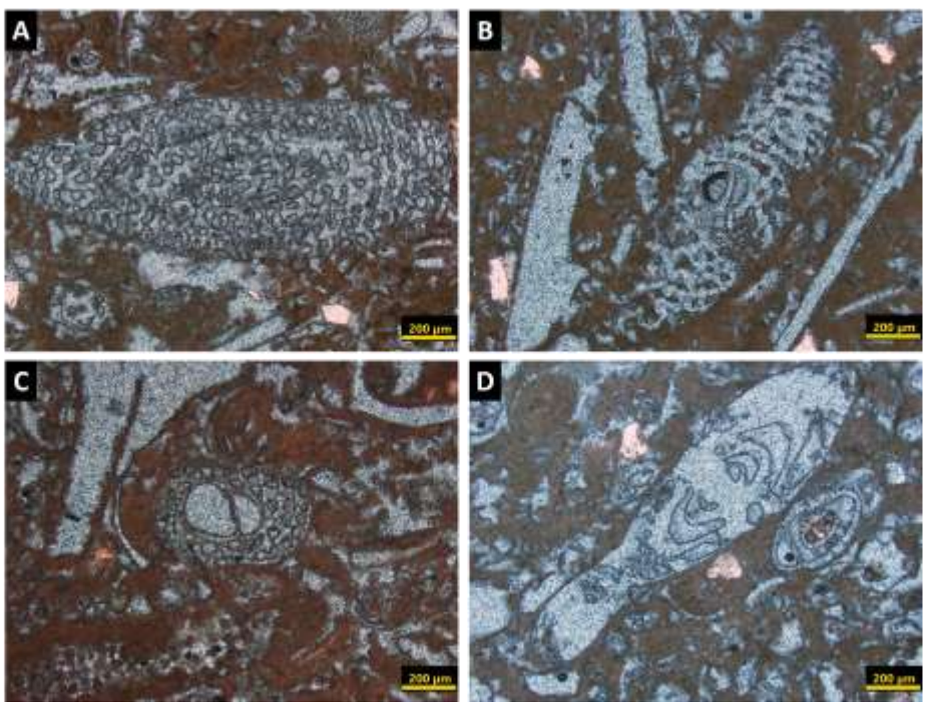


Figure 4.20 Thin section imange shows larger foraminiferal fragments found in sample 10. (A) alveolinids, (B, C) lepidocyclinids and (D) operculinids.

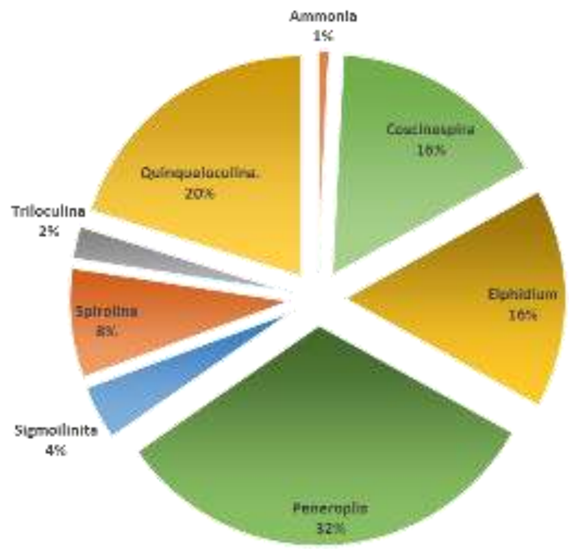


Figure 4.21 The percentage of main genera from Assemblage 8.

Section 1

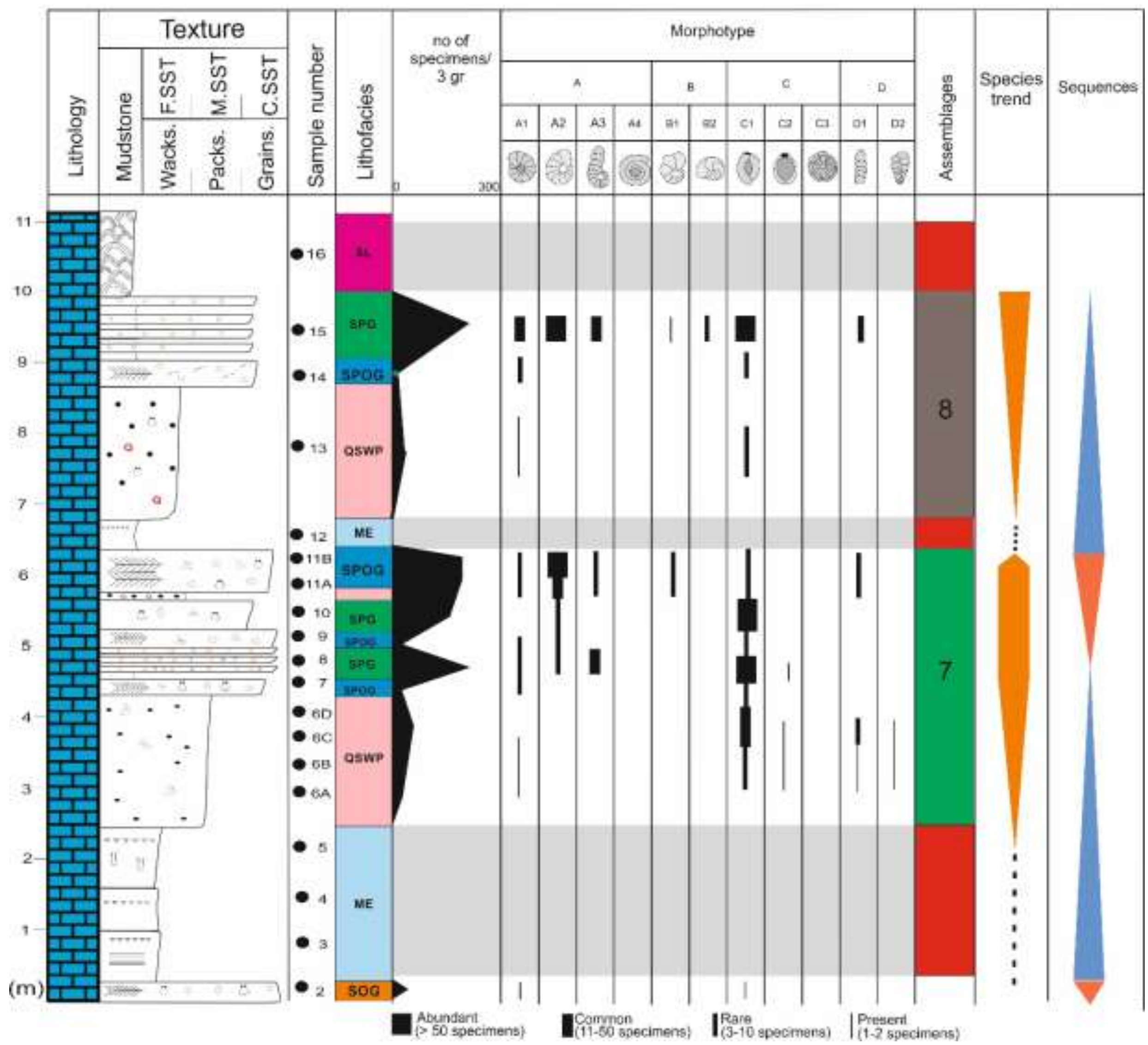


Figure 4.22 Stratigraphic column of section 1, showing the vertical distribution of specimens, morphotypes, species trends, and sequence stratigraphic interpretation.

Assemblage 9:

Five genera from a total 60 specimens were counted in this assemblage. Assemblage 9 was in the lower part of outcrop 2 (Figure 4.26). The main genera identified in this assemblages consist of *Quinqueloculina* (39%), *Peneroplis* (31%), followed by *Elphidium* (13%), *Ammonia* (6%), and *Stilostomella* (11%) (Figure 4.18) and the presence of gastropods and bivalves.

Assemblage 10:

Similar to assemblage 7, this assemblage is characterized by a high diversity of foraminiferal taxa and is located in the middle of outcrop 2. The most characteristic morphotype of this assemblages is C1, followed by A2, and A1 (Figure 4.21). About 470 specimens were counted from this assemblage. The most common genera includes *Quinqueloculina* (44%) *Peneroplis* (27%), *Elphidium* (15%), *Coscinospira* (5%), with *Triloculina, Sigmolinita, Ammonia,* and *Stilostomella* each comprising 2%. *Spirolina, Pyrgo, Planorbulina, Discorbinella, Amphistegina* each accounts for about 1% (Figure 4.24).

Assemblage 11:

This assemblage consists of 150 specimens of foraminifera and is located in the upper part of section 2 (Figure 4.26). Nine genera were identified on this assemblage, characterized by the dominance of the C1 morphotype, and by the genera *Quinqueloculina* (38%), *Peneroplis* (10%), *Ammonia* (10%), *Elphidium* (8%), *Coscinospira* (8%), *Spirolina* (5%), *Sigmoilinita* (3%), and *Textularia* (2%) (Figure 4.25). Eight morphotypes were identified, with abundant morphotype C1, followed by rare to common A1, A2. A3, B2, D1, and presence of the D2 morphotype (Figure 4.26).

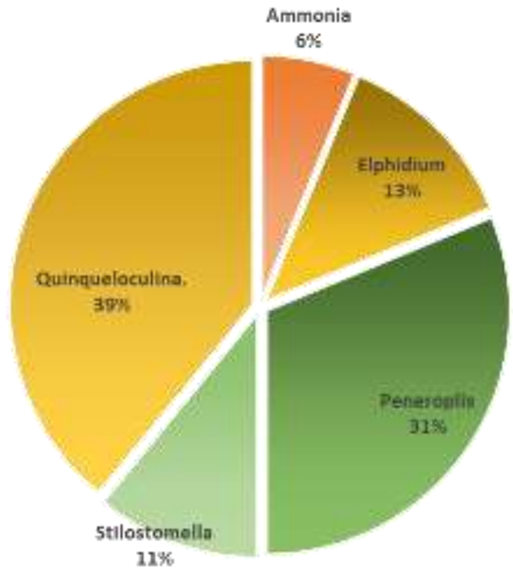


Figure 4.23 The percentage of main genera from Assemblage 9.

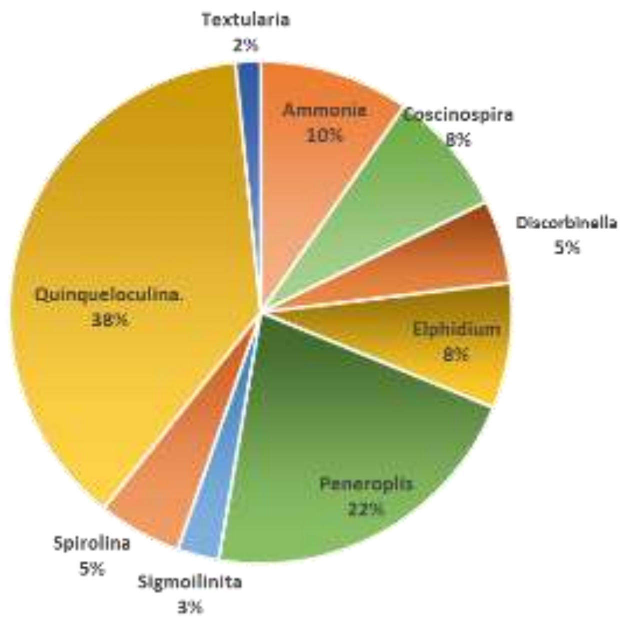


Figure 4.24 The percentage of main genera from Assemblage 11.

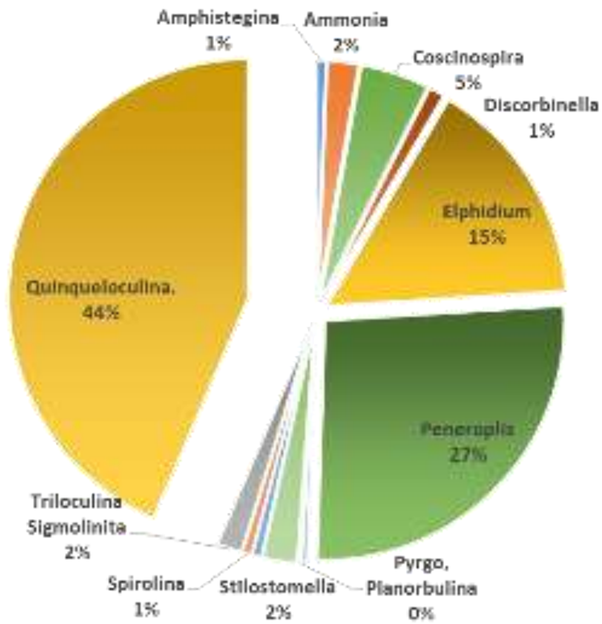


Figure 4.25 The percentage of main genera from Assemblage 10.

Section 2

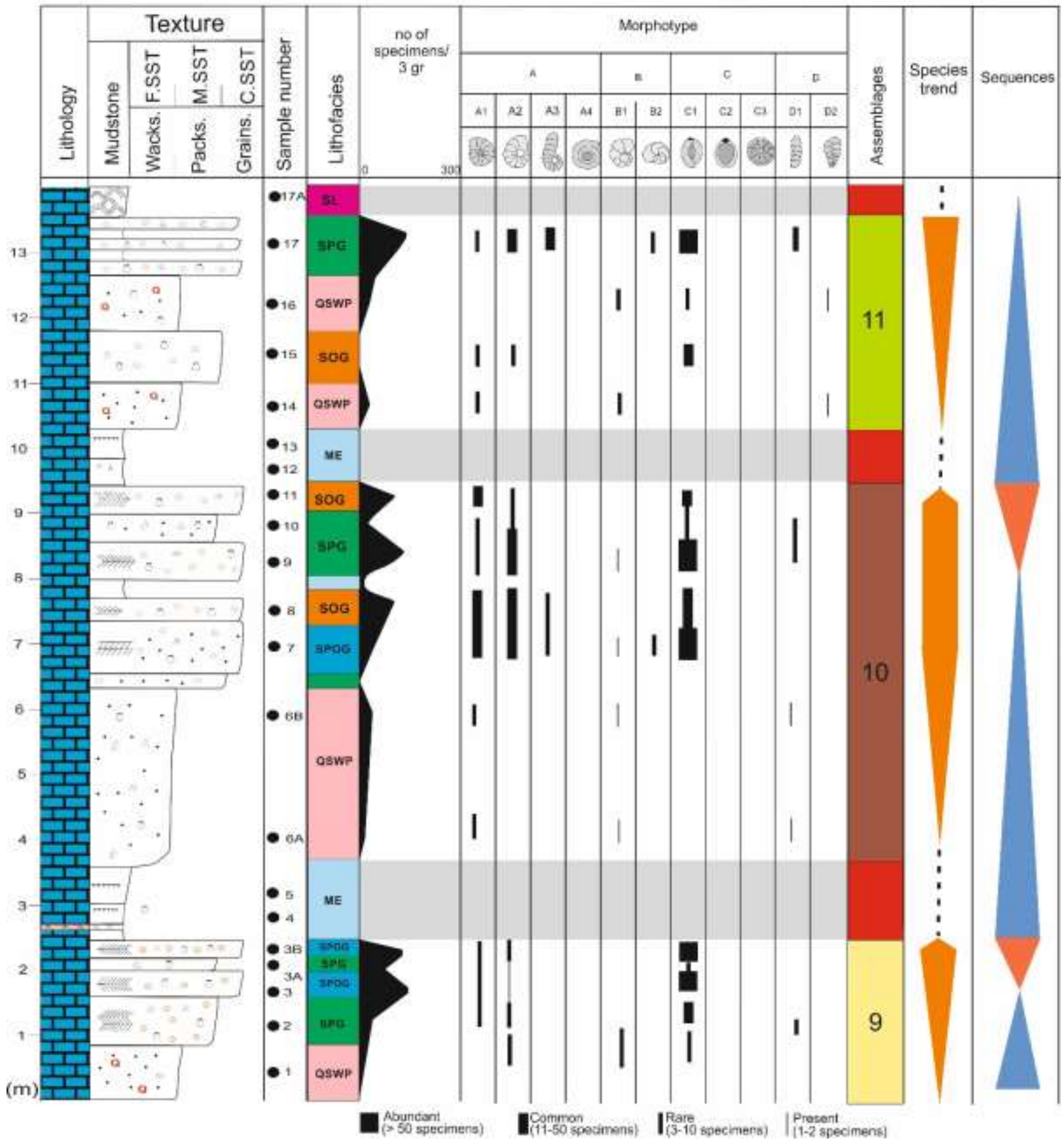


Figure 4.26 Stratigraphic column of section 2, showing the vertical distribution of specimens, morphotypes, species trends, and sequence interpretation of assemblages 9, 10, and 11.

CHAPTER 5

DISCUSSIONS

5.1. Acetic Acid Treatment

From the optimization of the acetic acid test, nearly all concentrations yielded promising results for disaggregation of carbonate rocks. The best recovery of microfossils is observed for higher concentrations of acid left for a longer reaction time. Lower concentrations with longer processing time and high concentrations with very limited time result in higher number of partially dissolved foraminiferal, but we can still recognize and identify the specimens to the generic level. Some of the specimens, however, might be destroyed during the processing time. Unfortunately, this is uncontrollable as we are dealing with tiny fossils.

Results of this study indicate that the acetic acid method is successful for extracting foraminifera from lithified carbonate rocks without destroying the fossil contents. From the results, it is possible to count the abundance of the foraminiferal specimens, perform statistical analysis for depositional environment interpretation, and construct their stratigraphic distribution patterns in order to understand vertical and lateral variations of the foraminiferal assemblages. Using the acetic acid, it was possible to extract a marker fossil for Burdigalian age which is *Borelis melo melo* (Figure 5.1). Although most of the specimens were not well preserved due to the diagenesis after the deposition, *"the appearances of a bad fossil is more valuable than a good working hypothesis"* (Trumpy, 1971).

5.2. Age of Dam Formation

Biostratigraphic calibration for the age of the Dam Formation is difficult due to the lack of identified age-diagnostic microfossils such as planktonic foraminifera and also the fact that the Dam Formation is underlain and overlain by siliciclastic Hofuf and Hadrukh formations which have no age-constraining microfossils. Selected carbonate samples from the Dam Formation were also sent out for the study of calcareous nannofossils for age determination. However, the calcareous nannofossils samples did not yield any recovery.

Powers *et al*. (1966) and Powers (1968) dated the Dam Formation in Saudi Arabia as a Middle Miocene age based on the occurrence of *Ostrea latimarginata*, *Echinocyamus* sp, and the benthic foraminifera *Archaias angulatus*. Cavalier (1970) assigned a Middle to Late Miocene age to the Dam Formation in Qatar based on presence *Archaias angulatus*. On the other hand, Hewaidy (1991), and Khalifa and Mahmoud (1993) reported the age of the Dam Formation as Early to Middle Miocene (Burdigalian-Helvetian) from two studied sections in Qatar. Recent studies conducted from the southwestern Qatar by Al-Saad and Ibrahim (2002) and from Jabal Midra Al-Junubi in Eastern Saudi Arabia (Al-Enezi ,2006), used the occurrence of *Borelis melo melo* to assign a Burdigalian (late early Miocene).

The benthic foraminifera *Borelis melo melo* provides an evidence of a late early Miocene to early Middle Miocene age, and has been reported by studies carried out on shallow marine, and lagoonal carbonates from the Mediterranean region (Adams, 1976; 1984), from the Qom Formation in Iran (Daneshian and Dana, 2004; Reuter *et al.*, 2009), from the Asmari Formation in the northwest of the Zagros Basin (Vaziri-Moghaddam *et al.*, 2010; Shabafrooz *et al.*, 2015. Heidari *et al.* (2014) and Hughes (2014) reported the benthic foraminiferal index species from the SE Zagros Basin in south Iran, and the Wadi Waqb member in NW Saudi Arabia, respectively.

The Dam Formation in the Al-Lidam escarpment, therefore, is assigned a Burdigalian (early late Miocene) age based on the presence of *Borelis melo melo* (Figure 5.1) found in one sample (sample 4A) in Outcrop 23 (Figure 4.15). According to Al-Khaldi (personal communication, 2016), the outcrops in the Al-Lidam area represent the middle part of the Dam Formation in general. This statement also supported by the existence of *Borelis melo melo*. The succession in the Al-Lidam area was likely deposited in a relatively shallower paleoenvironment compared to the Dam Formation reported from southwest Qatar and the Dammam Dome area. According to Sharland *et al.* (2001) the Dam Formation represents the maximum flooding surface event MFS Ng20.

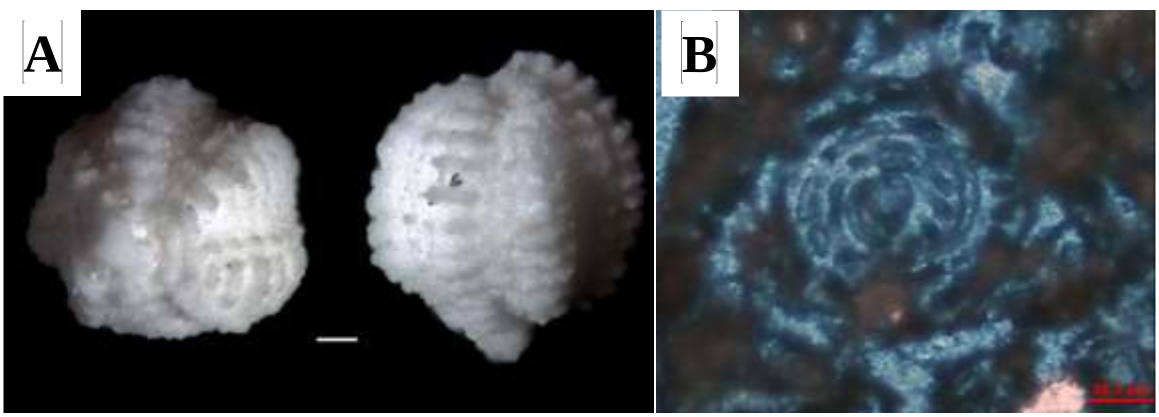


Figure 5.1 Mold of *Borelis melo melo* from acetic acid disaggregation. Scale: 100 µm (A) and Borelis melo melo presence in thin section (B).

5.3. Depositional Environment

The high percentage of calcareous porcellaneous fauna which prevails over the hyaline Rotaliina taxa, followed by a minor proportion of Textularina (Figure 4.10A), the absence of planktonic foraminifera, and all of the dominant genera present in this study (Figure 4.10B) reveals that the Dam Formation was deposited on a restricted carbonate platform (Figure 5.2C). The environment was a hypersaline very shallow marine with a gently sloping ramp (inner ramp) (Figure 5.2A, B).

The Miliolina (porcellaneous foraminifera) are the dominant suborder found within the studied samples (Figure 4.10A), and are presents in almost all lithofacies except in Mudstone Evaporites (ME), Sandstone and Mudstone (SM), and Stromatolitic Limestone (SL). The abundance of Miliolina is an indication of warm to temperate inner shelf shallow water as described by Gonera (2012). They normally thrive in both normal and also high saline environments (Brasier, 1975; Hottinger *et al.* 1993; Haunold *et al.* 1997; Cherif *et al*. 1997). *Peneroplis*, *Quinqueloculina*, *Triloculina, Elphidium*, and *Ammonia* taxa are widely developed within lagoonal sub-environments in the Arabian Gulf (e.g., Murray, 1991; Amao *et al.* in press).

The abundances of *Quinqueloculina* and *Triloculina* which are dominantly found in the SPG, SPOG, SOG, and QSWP lithofacies (Table 4.1) indicates the Dam Formation was deposited in a very hypersaline environment, with salinity ranging from 37 - 70‰, water temperature varying from 16 to 40°C (Murray, 1991), and water depth from 12 -18m (Murray, 2006; Parker and Gischler, 2015). The distribution of peneroplids especially in SOG, SPOG, and SPG lithofacies (Table 4.1) is related to the presence of vegetation within the very shallow marine or lagoon environment as their living behavior is usually epifaunal on the substrate, and epiphytic on seagrass or seaweed (Murray, 2006). Seagrass normally occurs in a shallow, subtidal environment to the intertidal zone because they are strongly influenced by light which they need for photosynthesis. The occurrence of *Elphidium* in the faunal assemblage (Figure 4.10D) also indicates that the environment is very shallow not deeper than a few to a dozen of meters. The green algae present in the canal system of the *Elphidium* shells need light requirements which is obtainable within a few meters of water depth (Leutenegger, 1984). Parker and Gischler (2015) reported that *Peneroplis* - *Elphidium* assemblages are typical of the inner ramp environment with water depths less than 5m (Figure 5.3). *Ammonia* is a common genus found in shallow-brackish-lagoonal environments (Martin, 1952; Murray, 1991).

Most of the genera present in recovered foraminiferal assemblages on this study are typical of high-energy environments characterized by high currents and tidal movements (Figure 5.2 and 5.3). The living habitat of foraminifers such as all miliolids (Miliolina), elphidiids (Elphidiidae), *Ammonia, Nonion, Cibicides*, and *Borelis* indicates they are free-living forms, mobile, and strong test form as a survival strategy for extremely agitated water conditions (Gonera, 2012). During deposition time, the study area was affected by tidal currents ranging from 1 to 2 m and strong wave current from persistent of NW shamal winds that generate waves several meters high (Jones, 2010).

The presence of reworked coral reef fragments and the existance of larger foraminifera such as alveolinids, lepidocyclinids, and operculinids (Figure 4.20) suggests the likely existence of a small patch reef in a shallow carbonate setting towards the basin (Figure 5.3). Tleel (1973) on his study in Dammam Dome area reported the Dam Formation in

Jabal Umm Er Rus in the Dammam Dome area as a reefal limestone (coral-algal) facies (Figure 5.3) and interpreted as a pinnacle reef environment. The absent of large and laterally continuous coral reef and a low percentage of larger foraminifera might be attributed to extreme salinity and the influx siliciclastic which are not favorable conditions for the development of coral reefs (Riegl *et al*. 2010).

The existence of stromatolites within the Dam Formation (Stromatolitic limestone lithofacies) supports the depositional environment interpretation. Algal stromatolites are typically formed under warm climatic conditions in a shallow subtidal to lower intertidal environment (Irtem, 1986). They normally developed when the deposition of detrital sediment to the coastal area was low or absent.

Based on the sedimentological description and the absence of foraminifera within the Mudstone and Evaporites (ME), Sandstone and Mudstone (SM), and Stromatolitic limestone (SL) lithofacies which indicate this three lithofacies were deposited in a continental area (supratidal to shallow intertidal) (Figure 5.3 A, B, C). The skeletal peloidal-oolitic grainstone (SPOG) characterized by the abundances of *Peneroplis*, *Elphidium*, and lower percentages of miliolids (*Quinqueloculina* and *Triloculina*) which indicate this lithofacies was deposited in a subtidal environment from inner ramp to oolitic shoal (Figure 5.3 D, E). The dominance of peloid and ooids is common in a shallow intertidal to subtidal carbonate system (Flugel, 2010). The percentage of miliolids are increased in Skeletal Peloidal packstone-grainstone (SPG) lithofacies which reveal more marine environment (middle ramp). Also by the presence of reworked coral fragments and larger foraminifera within this lithofacies which be a sign of presence patch reef (Figure 5.3). The Quartz skeletal wackstone – packstone lithofacies characterized by fine textures, structureless, and massive layers suggests a low energy environment. The foraminiferal faunal are rare, represents only by three to five specimens; *Elphidium* sp, miliolids, nodosariid, and *Textularia*. The presence of nodosariid and *Textularia* indicate deeper environment, lower middle ramp to outer ramp. The determination of depositional environment also supported by the comparison between Miocene Dam Formation with present day Arabian Gulf as discussed in the modern analogue sub-chapter.

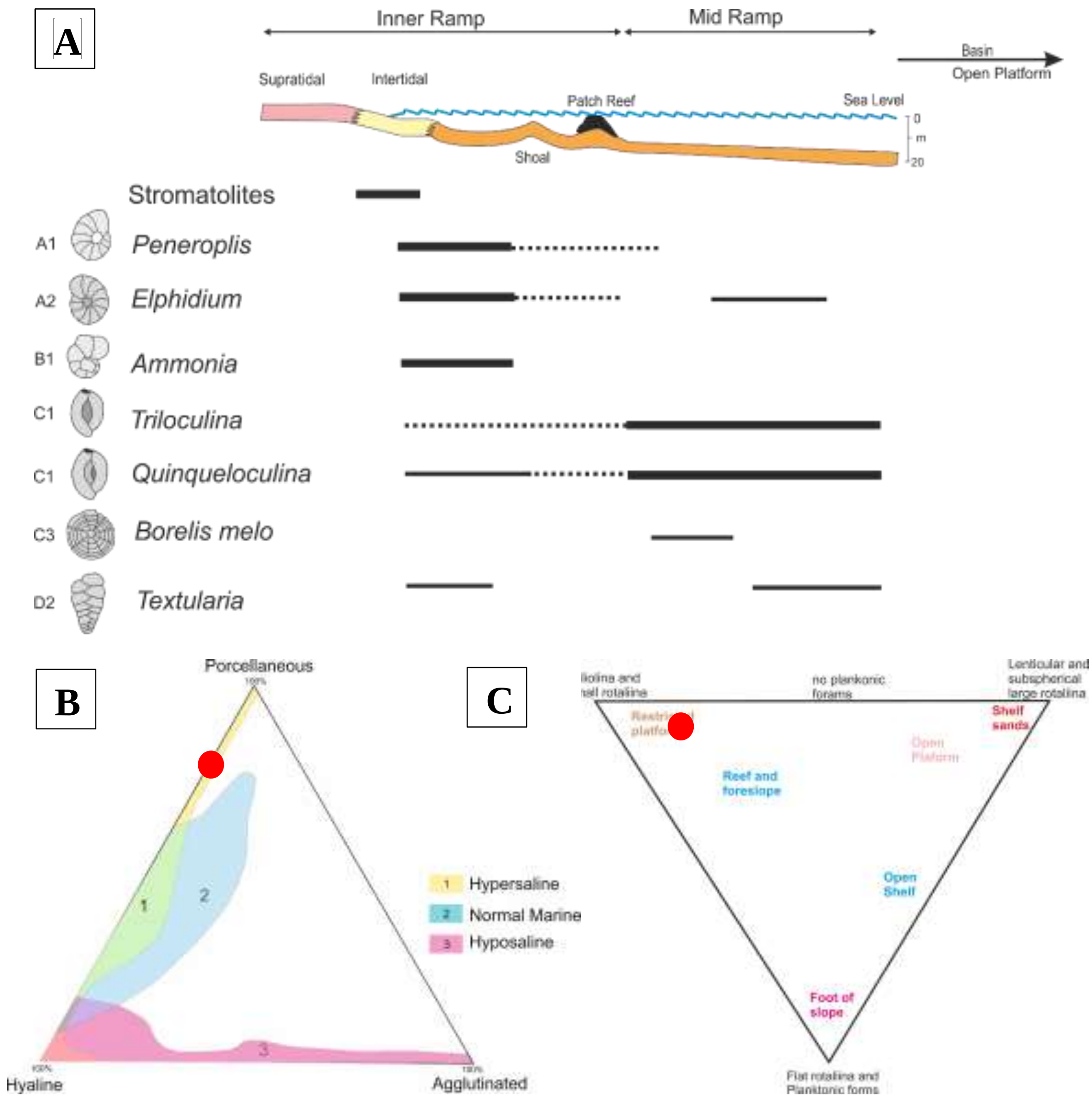


Figure 5.2 (A) Models of depositional environment of carbonate ramps characterized by the dominance of foraminifera. (B) Wall structures against environment which indicates a hypersaline condition. (C) Ternary plot based on the percentage of Miliolina and Rotaliina versus planktonic foraminifera, showing the Dam Formation was deposited on a restricted carbonate platform.

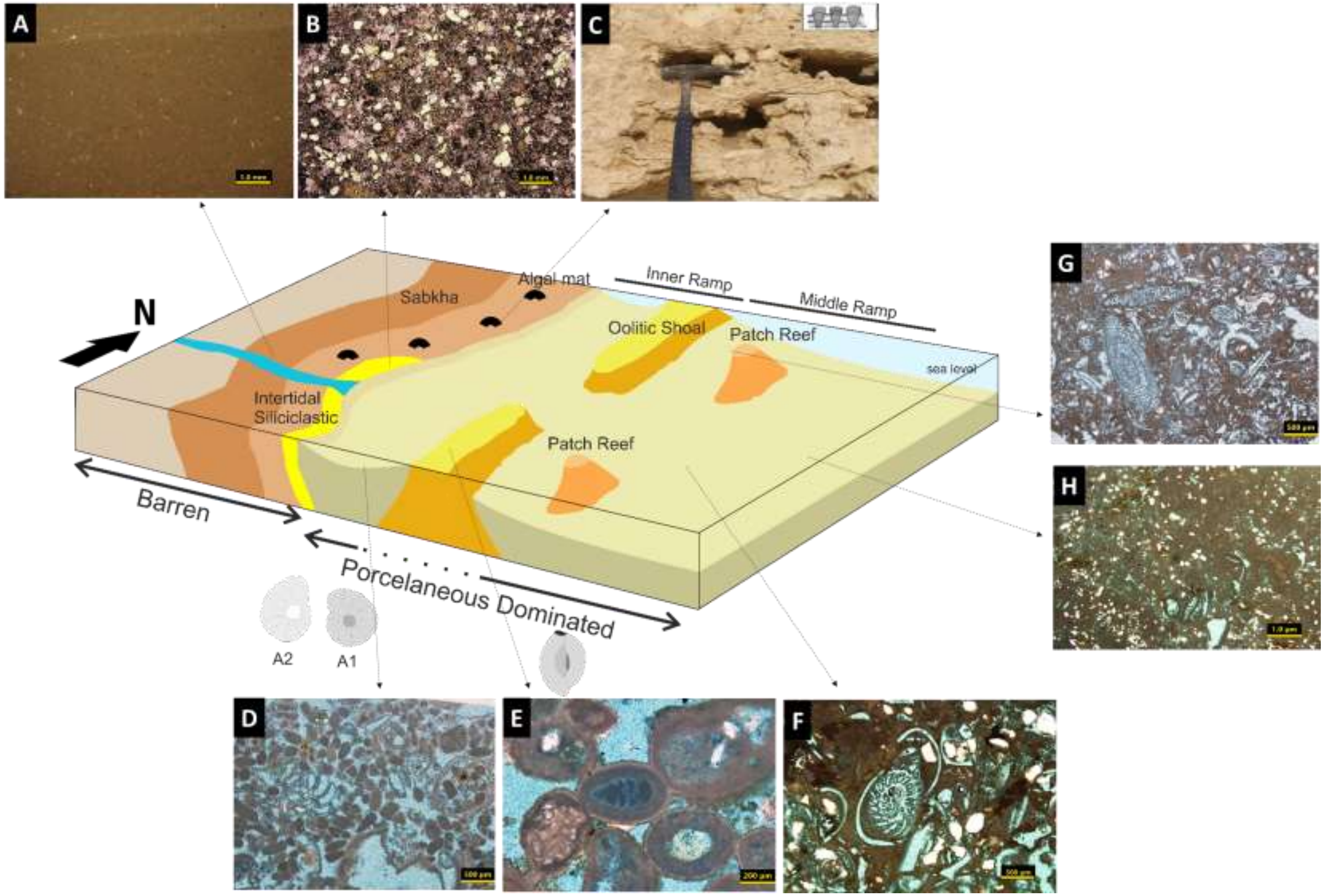


Figure 5.3 3D depositional model of Dam Formation for each lithofacies. Characterized by barren foraminiferal in the western side, and dominated by porcelaneous foraminifera in the inner ramp and middle ramp. (A) Mudstone and Evaporites (B) Sandstone and Mudstone (C) Stromatolites Limestone (D) Skeletal Peloidal – Oolitic Grainstone (E) Skeletal Oolitic Grainstone (F, G) Skeletal Packstone – Grainstone (H) Quartz Skeletal Wackstone – Packstone

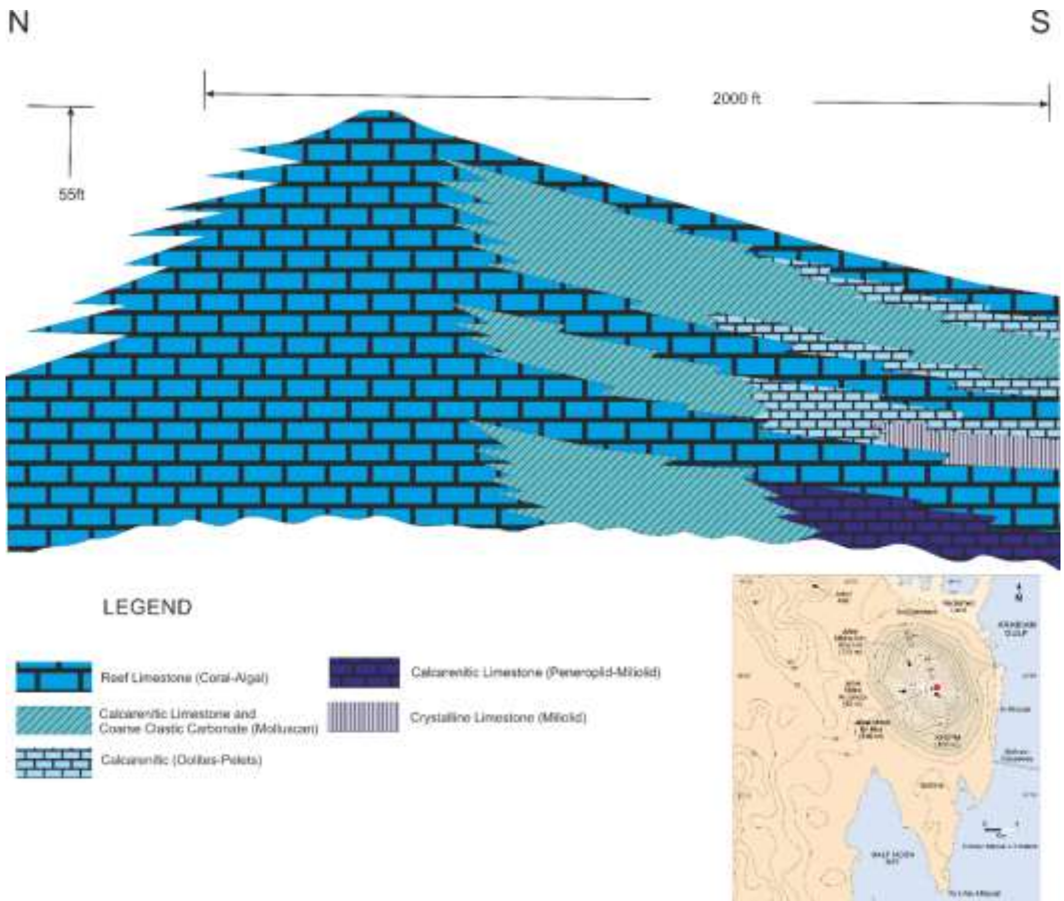


Figure 5.4 Schematic lithofacies section of the Dam Formation in Jabal Umm Er Rus (after Tleel, 1973).

5.4. Vertical and Lateral variations and Sequences Stratigraphy

Changes in the depositional environment are normally documented by the fossil record. The abundance and absence of microfossils in a sedimentary package would provide information of sea - level change, and provide information for the recognition of sequence boundaries. A sequence boundary typically marked by a decrease in species diversity, and in contrast, a marine transgression is clearly indicated by an increasing number of species (Murray, 2006).

In this study, three composite sequences were determined from each stratigraphic section respectively (Figure 5.5). According to Irtem (1986), the Dam Formation is consists of three upward-deepening cycles. The sequence boundary determined from each sedimentary package for each stratigraphic section clearly separated by the absence of foraminiferal assemblages. The assemblages increase during marine transgression while they decrease during the sea - level drop and a changed from marine to continental environment (Figure 5.4).

The biofacies trends used in sequence stratigraphic interpretation (Figure 5.5) was described by Nagy (2016). The author reported that a change in biofacies trends reflects a change in depositional conditions. An increase in foraminiferal diversity indicates an increase in water depth during transgression or an adaptation to marine conditions and in the proportion of taxa are due to a change in the depositional environment to the subaerial condition. The stratigraphic section below clearly indicates a changes in biofacies trends provides important information for the recognition of system tracts, sequence boundaries, and flooding events (Figure 5.4A). The sequence boundary was determined based on the reduction in the absolute abundance of the foraminiferal assemblage associated with the deposition of sabkha (mud and evaporites) while the flooding events were characterized by a high diversity of foraminifera in the peloidal - oolitic grainstone, and skeletal packstone-grainstone lithofacies.

The foraminiferal assemblage shows lateral variations the three main common genera found in each stratigraphic section (Figure 5.5B). The percentage of miliolid (*Quinqueloculina*, and *Triloculina*) increases toward the eastern direction especially in outcrop 1 and 2, while *Peneroplis*, and *Elphidium* dominate in the western sector represented by outcrop 8 and section 23 (Figure 5.5B). The increases proportion of miliolids indicates a more marine environment toward the east, moving from landward to seaward.

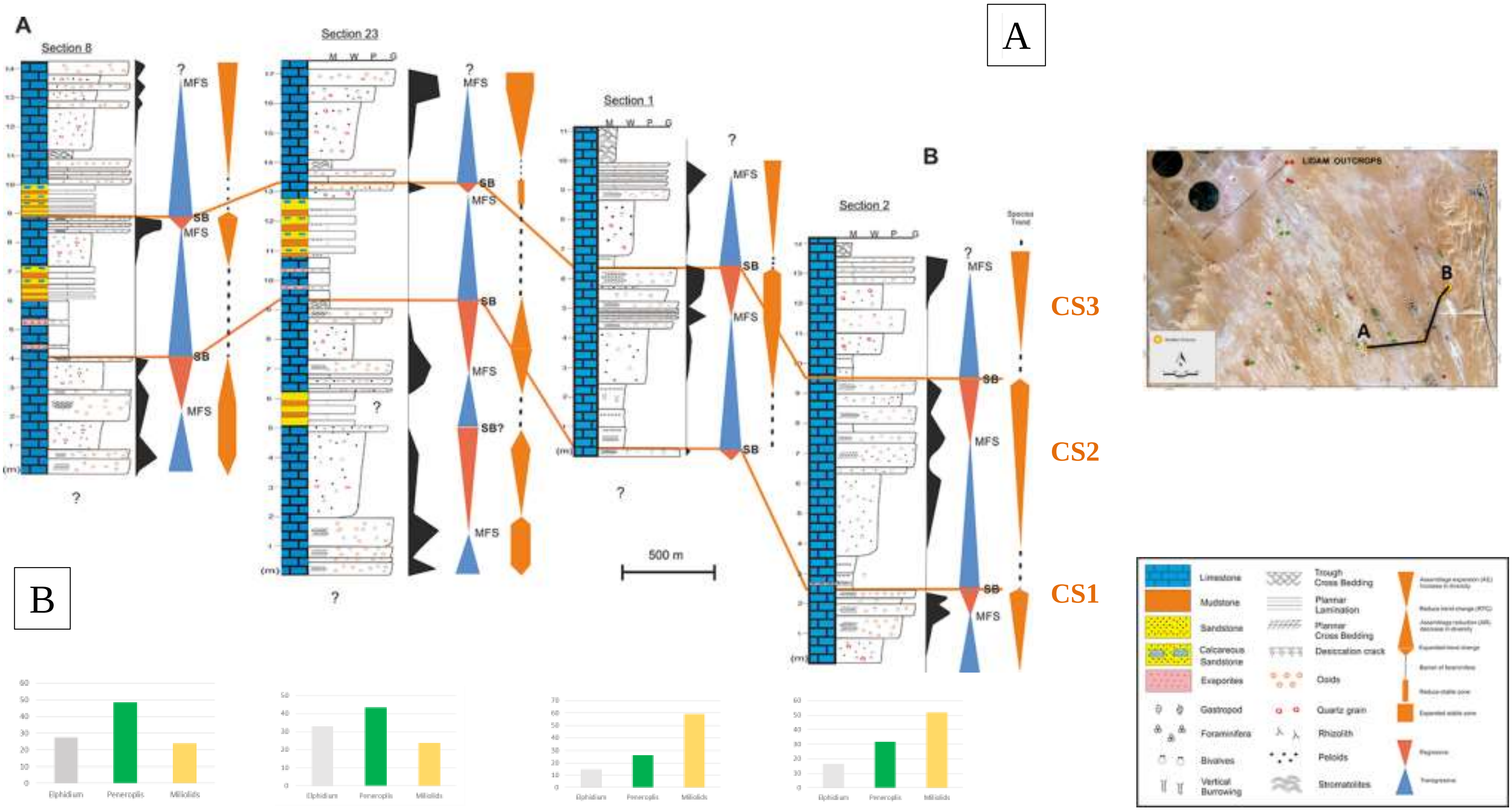


Figure 5.5 Sequence stratigraphic interpretation, lateral and vertical distribution of foraminiferal assemblages from the studied section (A). From the three common genera found, the Peneroplis is abundant in the western site whereas the percentage of miliolids (*Quinqueloculina* and *Triloculina*) increase toward the East.(B).

5.5. Modern Analogue

Based on the observed foraminiferal assemblage composition from the Miocene Dam Formation, the present day Arabian Gulf can be considered as a modern analogue for the formation. The ecological and climatic conditions have not changed significantly since the deposition of the Dam Formation in late early Miocene. In the modern Arabian Gulf, the waves currents range from 4-6 m (Loughland *et al*. 2012), tidal currents 0.4 to 4.2 m (Al-Zamel *et al*. 2009), and water temperature ranges from 20-35°C (Jones, 2010). The salinity ranges from 40-50‰ (Arslan *et al*. 2016) and reaches up to 70‰ in some restricted lagoons. The average rainfall is less than 100 mm/year (Koeshidayatullah *et al*. 2016) and the evaporation rates range from 140-400 mm/year (Reynolds, 1993).

The Arabian Gulf adjacent to the Arabian side (Figure 5.5A) called the Arabian shallow shelf or Arabian Homocline (Purser and Seibold, 1973) shows a complex interplay between carbonate, siliciclastic, and evaporite sedimentation (Strohmenger *et al*. 2011). It is also frequently cited as an example of a mixed carbonate-siliciclastic environment, and shallow seas carbonate ramp formed in an arid, subtropical climate environment. Regionally, the Arabian Gulf has been used as an analog for other formation such as Oligocene-Miocene Asmari Formation in SW Iran (Purser, 2012), and the Cretaceous Shuhaiba Formation in the Arabian Peninsula (Hughes, 1997).

The present day Arabian Homocline is characterized by a gently sloping ramp, very shallow marine, restricted hypersaline environment, and the development of sabkhas in a supratidal setting, microbial tidal flats, tidal lagoons, and tidal channels that prograde from intertidal into the shallow subtidal area. It is characterized by the presence of high energy skeletal-oolitic sand shoals in the subtidal area, and scattered coral reefs towards to the basin (Loreau and Purser, 1972; Riegl *et al*. 2010) (Figure 5.5B). The foraminiferal assemblages found in this study area are typical of a shallow intertidal to a subtidal environment. In he supratidal environments the foraminifera were absent.

Strong and persistent NW Shamal winds often generate several meters high waves especially during the summer time between June and August (Riegl *et al*. 2010). These waves are among one of the mechanisms which are responsible for supplying abundant siliciclastic materials to the sea (Figure 5.5B), mixed with the deposition of carbonate. Other mechanisms that contribute to the existence of clastic contents are coastal dunes and beach sands reworked in the foreshore environment (Wilson, 1975).

Several authors have investigated modern foraminifera from different parts of the Arabian shallow shelf. These studies include those from the southern Arabian margin (Murray, 1965b, 1966a, b, c; Hughes Clark and Keij, (1973), and Cherif *et al*. (1997), from Tarut bay Saudi Arabia (Ahmed, 1991), from eastern Bahrain (Basson and Murray, 1995; Arslan et al. 2015), from Qatar (Hitmi and Hitmi, 2000). Parker and Gischler (2015) studied the foraminiferal distribution from Kuwait Bay while the foreshore in eastern Bahrain and a small lagoon in eastern Bahrain Arslan *et al.* (2016), and Amao *et al*. (2016) respectively. The above- listed studies reported foraminiferal faunas dominated by porcellaneous taxa (*Quinqueloculina*, *Triloculina*, *Peneroplis*, *Coscinospira*) from shallow waters (<18 m depth) of the Arabian Gulf. On the other hand, the hyaline forms increase basinward; hyaline foraminifera dominates at water depths greater than 18 m (Figure 5.6). All of the foraminiferal faunas reported indicate a hypersaline environment.

The morphotype analysis of the current study shows more than 70% planispiral morphotypes dominate depths ranging from 0 to 5 m while milioline morphotypes are predominant from 5 to 18 m water depth. A mix of trochospiral, planispiral, and milioline are found at water depths greater than 18 m, epifaunal taxa are dominant in water depths less than 5 m whereas infaunal taxa are abundant in the deep waters ranging from 5 to 16 m (Parker and Gischler, 2015).

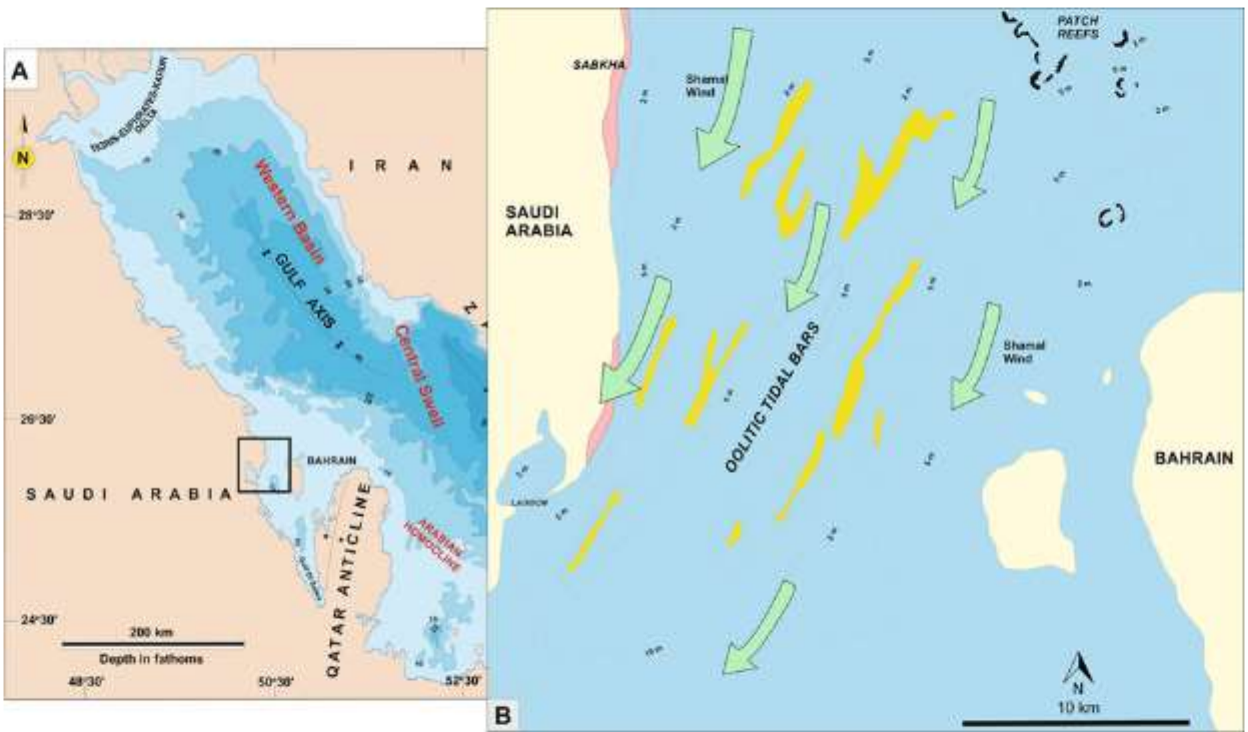


Figure 5.6 (A) Bathymetric map of the Arabian Gulf showing the shallowest part adjacent the Arabian site and deeper towards the Iranian area (after Strohmenger et al. 2011). (B) Closer view of present day Arabian Gulf between Saudi Arabia and Bahrain showing the deposition of sabkha in the continental area (supratidal), oolitic sand in subtidal environments, and the distribution of patch reefs in the open marine environment. The persistent of northwest shamal winds supply abundant siliciclastic materials and deposit them in the marine environment. Figure modified from Loreau and Purser (1973).

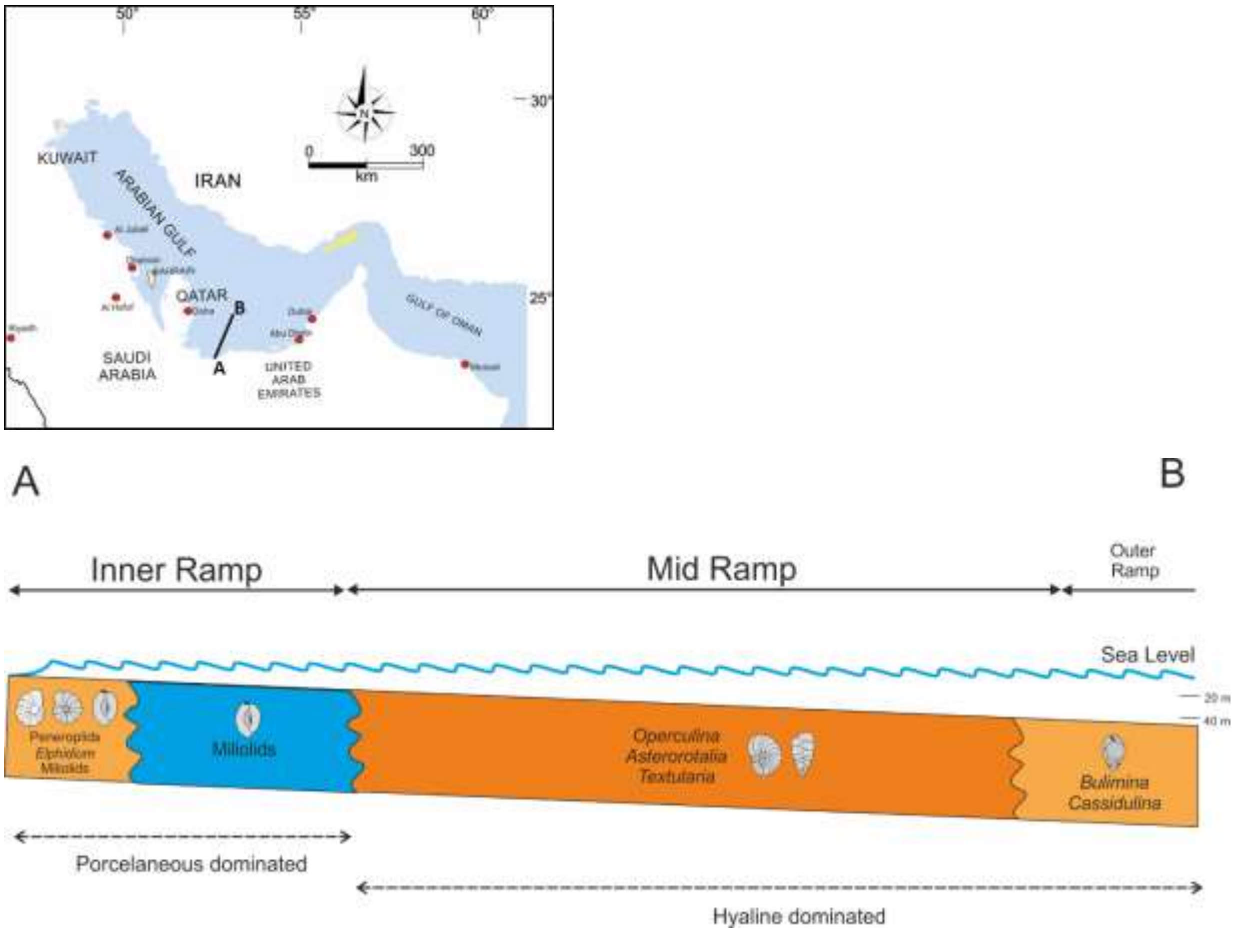


Figure 5.7 Distribution of foraminifera along the southern Arabian transect. The porcelleneous dominated in the shallowest part where the hyaline forms abundant in the depth greater than 18 m (modified from Parker and Gischler, 2015).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The acetic acid method was successful for extracting foraminifera from lithified carbonate rocks without destroying the fossil content. From the results obtained it is possible to count the abundance of specimens, determine morphotype, and perform statistical analysis for depositional environment interpretation.

Eleven foraminiferal morphotypes were determined in this study and are designated alphabetically: (A1) Biconvex Planispiral, (A2) Flattened depressed Planispiral, (A3) Uncoiling Planispiral, (A4) Tubular Planispiral, (B1) Biconvex Planispiral, (B2) Planoconvex Tochospiral, (C1) Miliolid-Quinqueloculina-Triloculina, (C2) Miliolid-Pyrgo, (C3) Miliolid-Fusiform spherical, (D1) Cylindrical Uniserial, and (D2) Agglutinated Biserial. The morphotypes identified in this study, are dominated by (C1) Miliolid-Quinqueloculina-Triloculina (40%), (A2) Flattened depressed Planispiral (26%), and (A1) biconvex planispiral, which represent 40%, 26%, and 19% of the assemblage, respectively. The other eight morphotypes occur as minor constituents of the assemblages, each amounting to between 1% and 8%.

A total of 46 benthic foraminiferal species that belong to 24 genera, representing 16 families, and 3 suborders was identified from the Dam Formation. The assemblages are characterized by the dominance of calcareous porcellaneous which account for 75%

(*Quinqueloculina, Peneroplis, Triloculina, Cornuspira, Sigmoilinita, Coscinospira, Spirolina, Pyrgo, Borelis*). Rotaliina account for 24% (*Elphidium, Ammonia, Cibicides, Discorbinella*) and 1% of the assemblage consists of agglutinated Textularina taxa. Eleven foraminiferal assemblages were recognized in the Dam Formation, and these clearly show vertical and lateral variations, and assist in the determination of the sequence boundaries and maximum flooding surfaces.

Based on the presence of *Borelis melo melo*, the age of the Dam Formation in the Al-Lidam escarpment was assigned as Burdigalian (late early Miocene). The species *Borelis melo melo* has been reported by several authors in deposits of late early Miocene to early Middle Miocene age.

The high percentage of calcareous porcellaneous fauna which prevail over hyaline Rotaliina taxa, followed by a minor percentage of Textularina, the absence of planktonic foraminifera, and all of the dominant genera present in this formation suggest that the Dam Formation was deposited on a restricted carbonate platform in very shallow marine or hypersaline lagoonal environment on a gently sloping ramp (inner ramp).

Based on the observed foraminiferal assemblage composition from the Miocene Dam Formation, the present day Arabian Gulf can be considered as a modern analog. The current environmental conditions have not changed significantly since the deposition of the Dam Formation in late early Miocene time.

6.2 Recommendations

Additional necessary investigations need to be done in the future due to some limitations encountered in this study. Therefore, the following points are recommended for further investigations:

1. To extend the study area outside the Al-Lidam escarpment to follow the distribution of foraminiferal assemblages, and foraminiferal morphotypes.
2. Conduct several transects along the Arabian Gulf on the Arabian side, i.e., Half Moon Bay, Gulf of Salwa. Count the percentage of modern foraminifera, do a grain size analysis, in order to determine the distribution of foraminifera along a bathymetric transect in the modern seas.

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APPENDIX A - Tables

SECTION 8.

Samples no.	Main Genera																								Others	
	Amphistegina	*Ammonia*	*Borelis melo*	*Cibicides*	*Cibicidoides*	*Coscinospira*	*Cornuspira*	*Discorbinella*	*Discorbis*	*Elphidium*	*Operculina*	*Peneroplis*	*Planorbulina*	*Pullenia*	*Pseudotriloculina*	*Pyrgo*	*Rotalia*	*Stilostomella*	*Sigmoilinita*	*Spirolina*	*Triloculina*	*Quinqueloculina.*	*Textularia*	Ostracods	Bivalve	Gastropod
15						**5**				**10**		**15**								**5**		**15**				
b																						**2**				
14						**10**				**15**		**20**								**4**		**10**				
a										**3**												**4**				
13						**8**				**10**		**14**										**6**				
12										**2**												**3**				
11																										
10		**3**			**5**	**30**				**10**		**30**						**10**		**5**		**40**			**5**	**12**
9b																										
8						**25**		**5**		**10**		**60**						**15**	**10**	**8**		**45**				
7																										
6																										
5		**5**								**15**		**40**										**10**				
4a		**2**								**1**												**3**	**1**			
4		**6**								**12**		**55**										**5**				
3										**6**						**1**					**10**	**35**				
2		**2**								**2**													**1**			
1		**5**								**12**		**55**										**5**				

SECTION 23.

Samples no.	Main Genera																								Others	
	Amphistegina	*Ammonia*	*Borelis melo*	*Cibicides*	*Cibicidoides*	*Coscinospira*	*Cornuspira*	*Discorbinella*	*Discorbis*	*Elphidium*	*Operculina*	*Peneroplis*	*Planorbulina*	*Pullenia*	*Pseudotriloculina*	*Pyrgo*	*Rotalia*	*Stilostomella*	*Sigmoilinita*	*Spirolina*	*Triloculina*	*Quinqueloculina.*	*Textularia*	Ostracods	Bivalve	Gastropod
22				**2**		**20**	**5**			**30**	**2**	**40**		**5**				**5**		**10**	**6**	**20**				
21						**30**	**3**			**40**	**5**	**50**		**3**						**15**	**5**	**10**				
20a										**5**												**4**				
20										**3**												**2**				
19																										
18a							**5**			**3**												**15**				
15																										
13																										
12												**5**														
11										**4**																
10																										
9b							**5**	**10**		**15**		**8**				**2**			**5**		**10**	**40**				
9							**3**			**10**		**5**										**15**				
8																					**2**	**5**				
7										**3**												**2**				
6																										
5										**3**												**2**				
4a			**1**			**5**				**10**		**15**									**8**	**10**	**1**		**2**	
4				**5**														**4**							**5**	**10**
3				**5**		**10**	**3**	**5**		**30**		**10**						**5**			**5**	**15**				
2										**10**																
1												**50**														

SECTION 1.

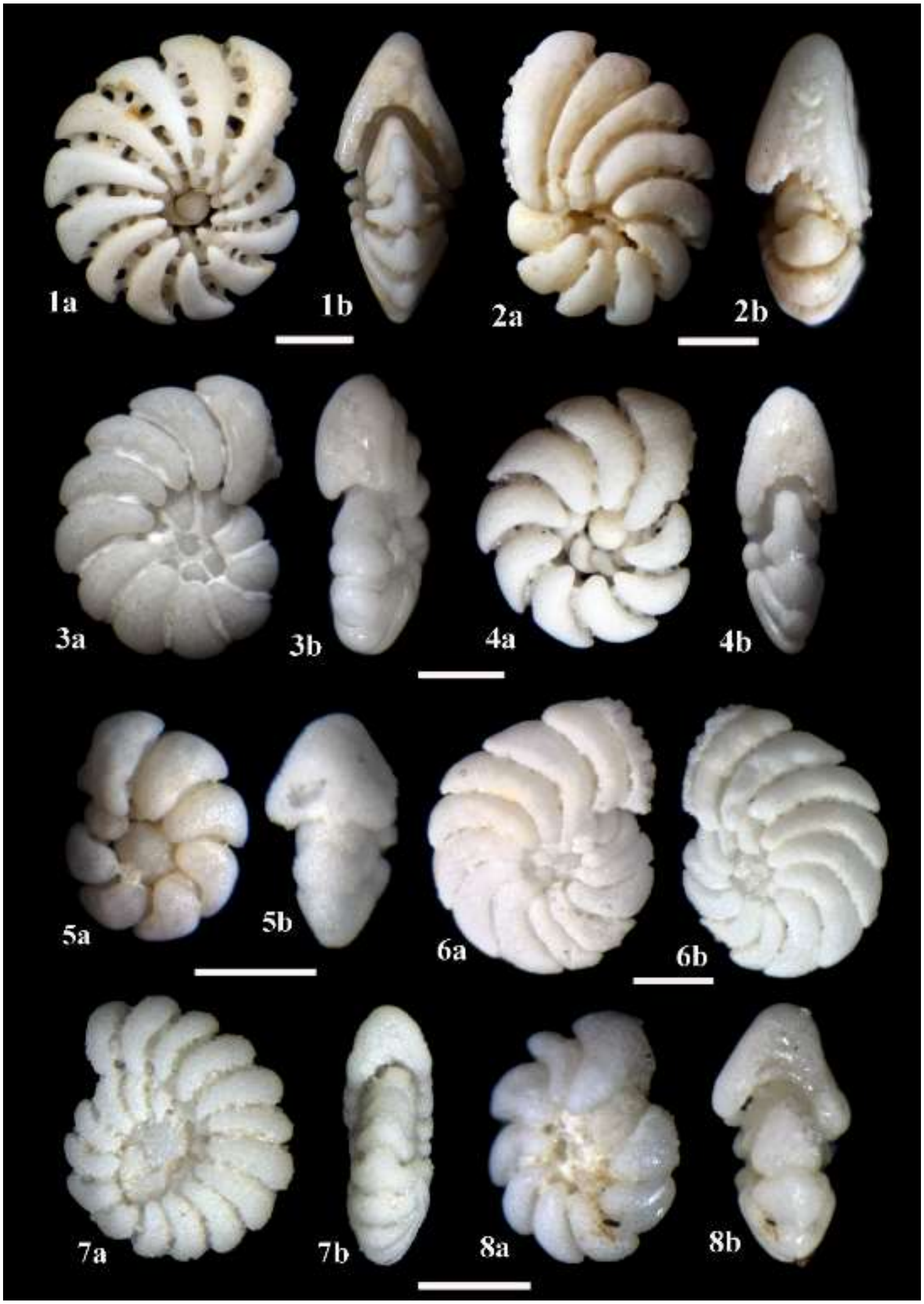
Samples no.	Main Genera																								Others	
	Amphistegina	*Ammonia*	*Borelis melo*	*Cibicides*	*Cibicidoides*	*Coscinospira*	*Cornuspira*	*Discorbinella*	*Discorbis*	*Elphidium*	*Operculina*	*Peneroplis*	*Planorbulina*	*Pullenia*	*Pseudotriloculina*	*Pyrgo*	*Rotalia*	*Stilostomella*	*Sigmoilinita*	*Spirolina*	*Triloculina*	*Quinqueloculina.*	*Textularia*	Ostracods	Bivalve	Gastropod
16						**20**				**10**		**40**							**5**	**10**		**10**				
15																										
14										**10**											**3**	**10**		**1**		**1**
13		**1**																				**5**			**15**	
12																										
11b		**3**		**2**		**15**			**2**	**20**		**60**					**2**	**3**				**45**				
11a		**5**		**1**		**10**			**4**	**15**		**50**					**2**	**5**				**40**				
10	**3**											**15**										**150**				
9										**10**		**16**										**5**				
8						**20**				**10**		**40**				**1**					**10**	**50**				
7										**10**											**3**	**10**		**1**		**1**
6d		**5**														**5**		**10**			**5**	**20**	**1**	**1**		**1**
6a		**3**								**4**						**2**		**3**			**4**	**16**				
5																										
4																										
3																										
2										**2**												**3**				

SECTION 2.

Samples no.	**Main Genera**																								**Others**	
	Amphistegina	*Ammonia*	*Borelis melo*	*Cibicides*	*Cibicidoides*	*Coscinospira*	*Cornuspira*	*Discorbinella*	*Discorbis*	*Elphidium*	*Operculina*	*Peneroplis*	*Planorbulina*	*Pullenia*	*Pseudotriloculina*	*Pyrgo*	*Rotalia*	*Stilostomella*	*Sigmoilinita*	*Spirolina*	*Triloculina*	*Quinqueloculina.*	*Textularia*	Ostracods	Bivalve	Gastropod
17a																										
17						**15**		**10**		**10**		**30**							**5**	**10**		**25**				
16		**8**																				**10**	**1**			
15										**5**		**10**										**15**				
14		**10**																				**20**	**2**			
13																										
12																										
11										**12**		**15**										**10**				
10										**13**		**30**						**2**				**20**				
9		**3**				**5**				**10**		**35**						**4**				**60**				
8						**7**				**12**		**20**								**3**		**30**				
7		**1**				**10**		**5**		**15**		**25**				**1**						**50**				
6d		**4**								**8**									**2**		**3**	**20**				
6a		**2**								**3**			**2**					**5**	**1**		**5**	**15**				
5																										
4																										
3b										**3**																
3a																									**5**	**10**
2		**3**								**5**		**10**						**7**				**15**				
1		**1**										**10**										**10**				

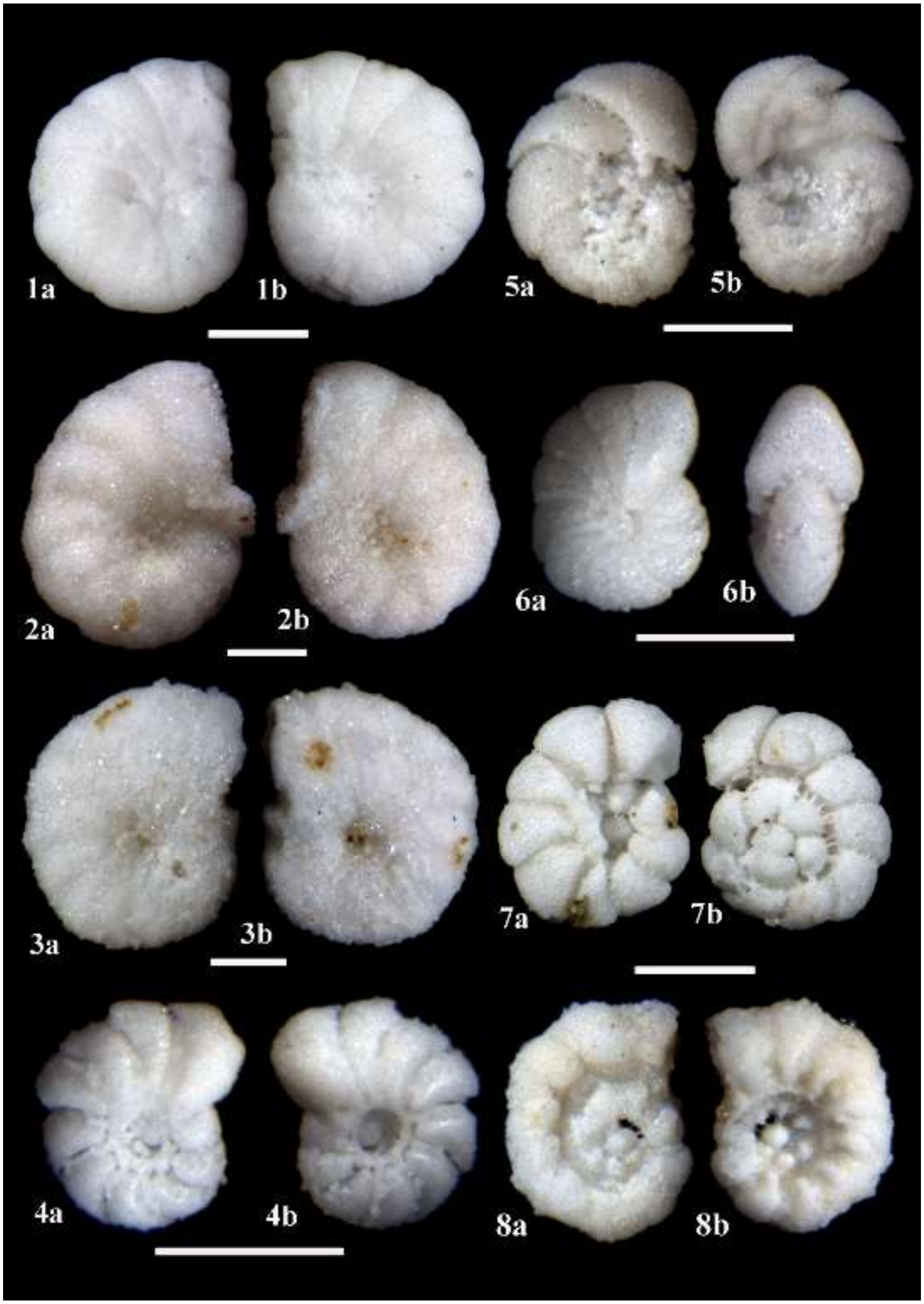
APPENDIX B - Plates

PLATE 1



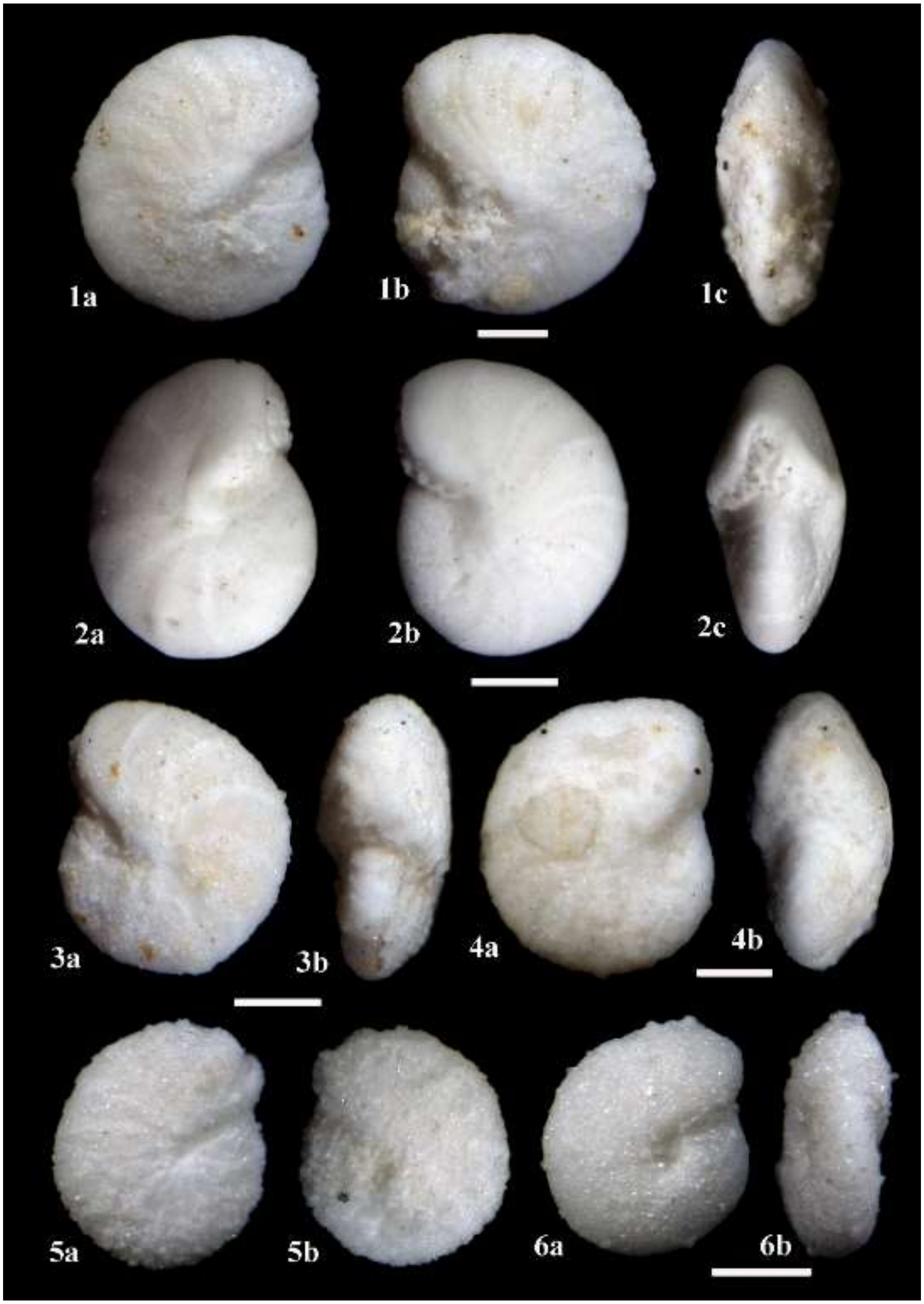
1. *Elphidium* sp. 1 (dissolved outer wall), S23/16. **2.** *Peneroplis* sp. 1, S8/2. **3.** *Peneroplis* sp. 2, S1/8. **4.** *Peneroplis* sp. 3, S8/14. **5**. *Peneroplis* sp. **6,** S1/10. **6.** *Peneroplis* sp. 7, S8/9. **7.** *Elphidium* sp. 2, S8/9. **8.** *Elphidium* sp. 3 (dissolved outer wall), S8/1.

PLATE 2



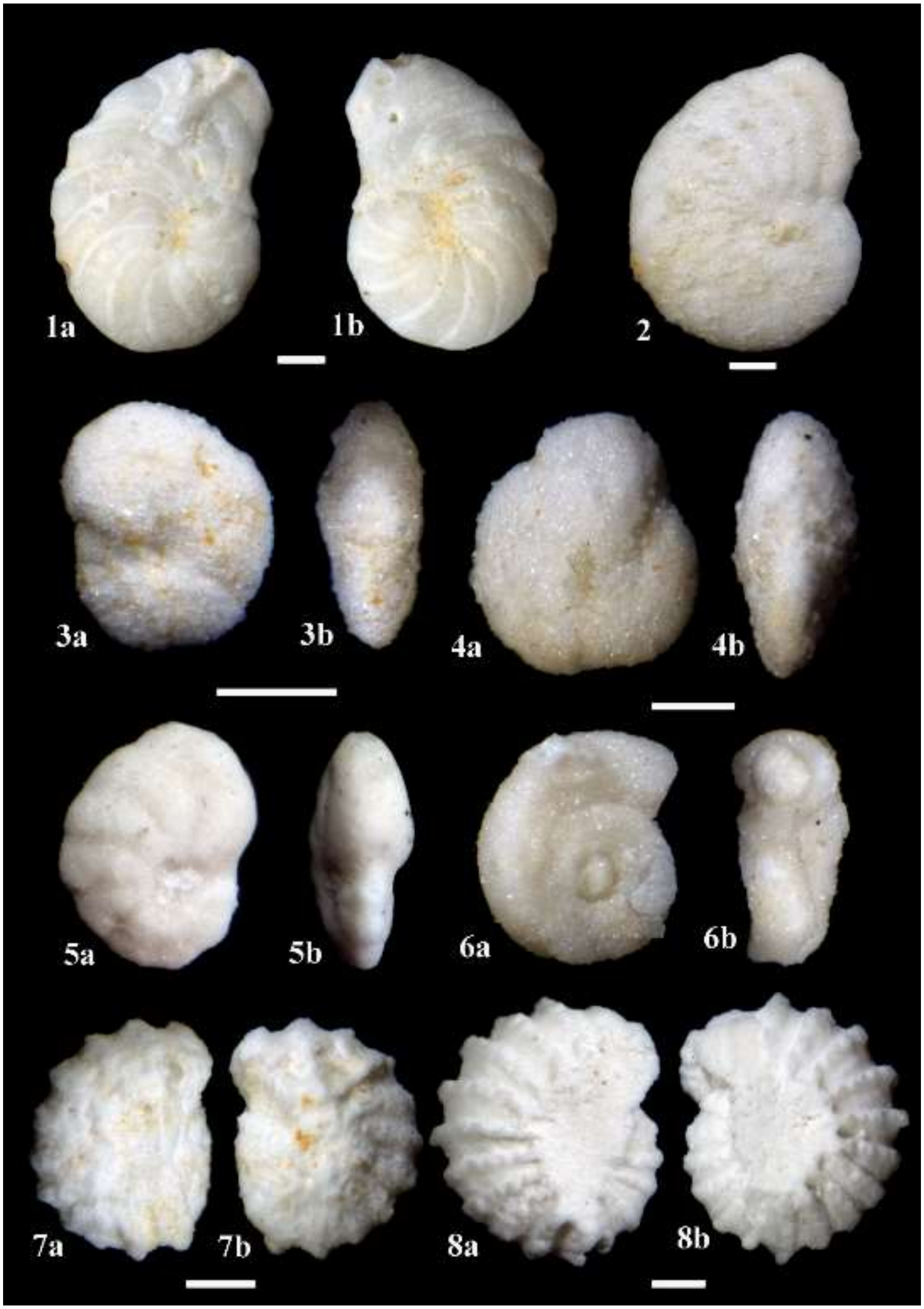
1-3 *Peneroplis* sp. 8, (1) S23/4a, (2) S8/9, (3) S23/21. **4, 6.** *Porosononion* sp, S1/6c. **5.** S1/6. **7.** *Ammonia* sp. S1/13. **8.** *Cibicidoides* sp. S8/10.

PLATE 3



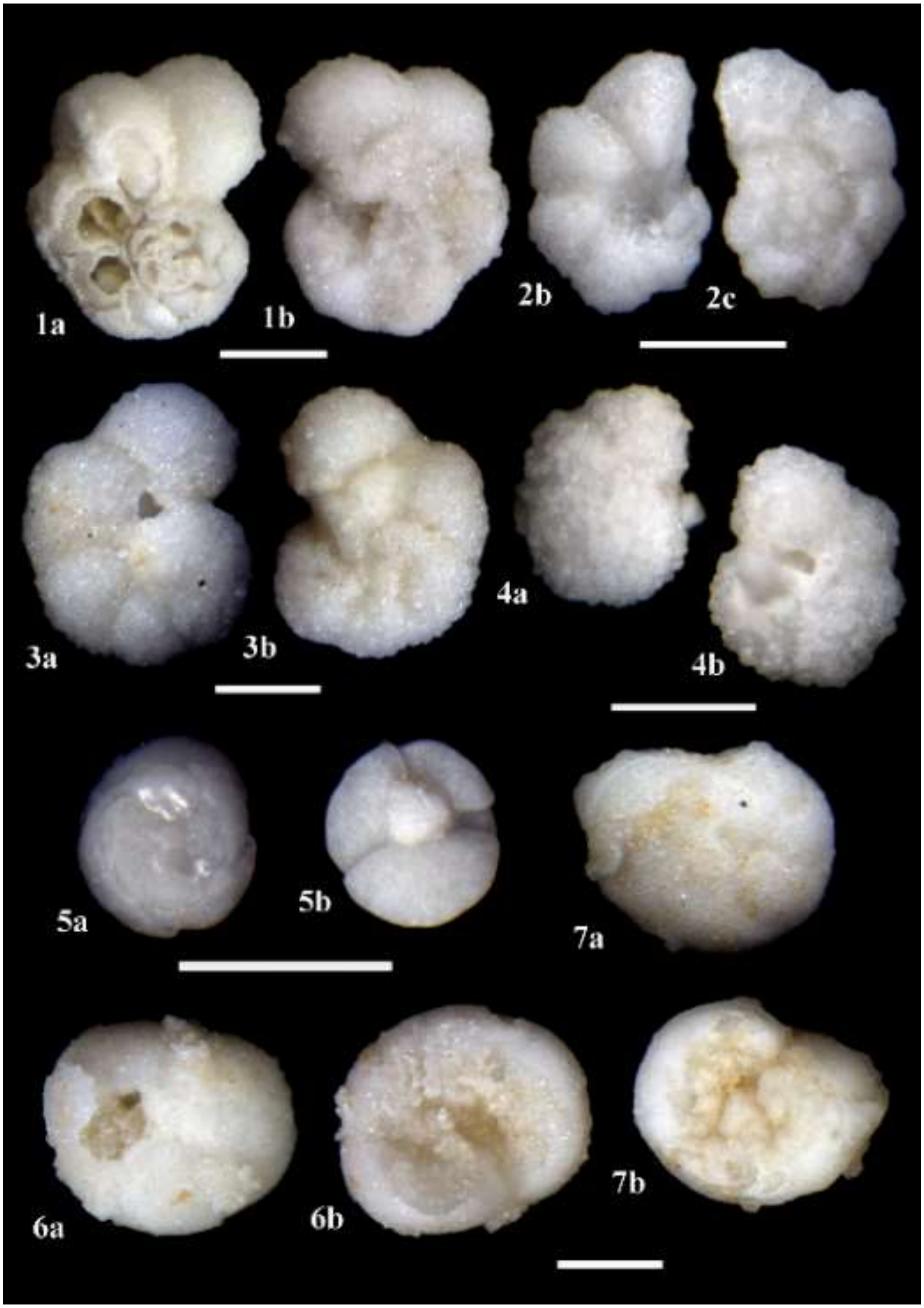
1 – 6. *Elphidium* sp. (1) S23/21, (2) S23/4a, (3) S23/22, (4) S1/11b, (5) S23/21, (6) S23/21.

PLATE 4



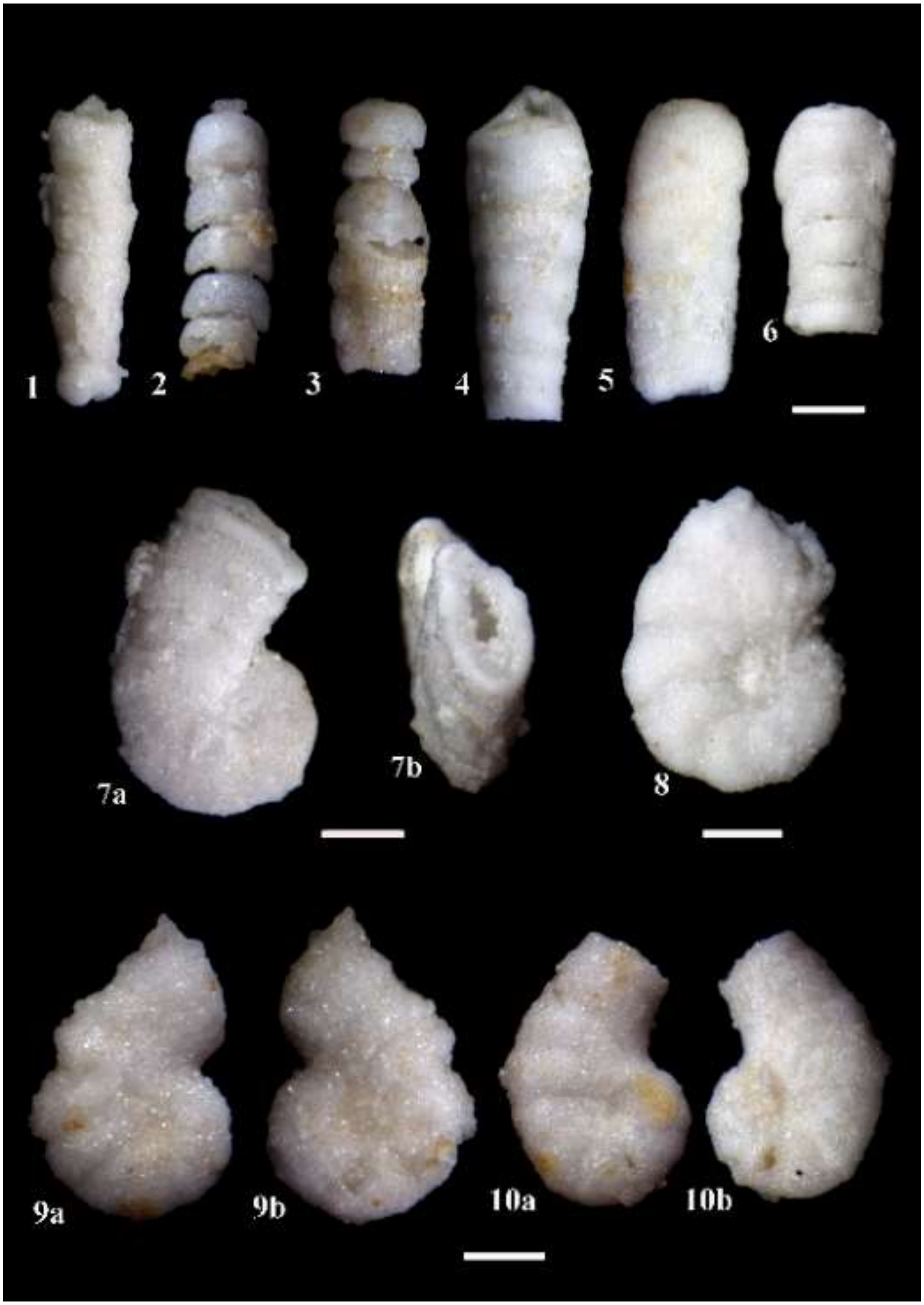
1. *Peneroplis* sp. 9, S23/22 **2**. *Operculina* sp. S23/21. **3, 4.** *Pullenia* sp. (3) S23/22, (4) S23/21. **5**. *Nonionella* sp. S23/11. **6**. *Cornuspira* sp. S1/11b. **7, 8** *Peneroplis* sp. 10, S23/4a.

PLATE 5



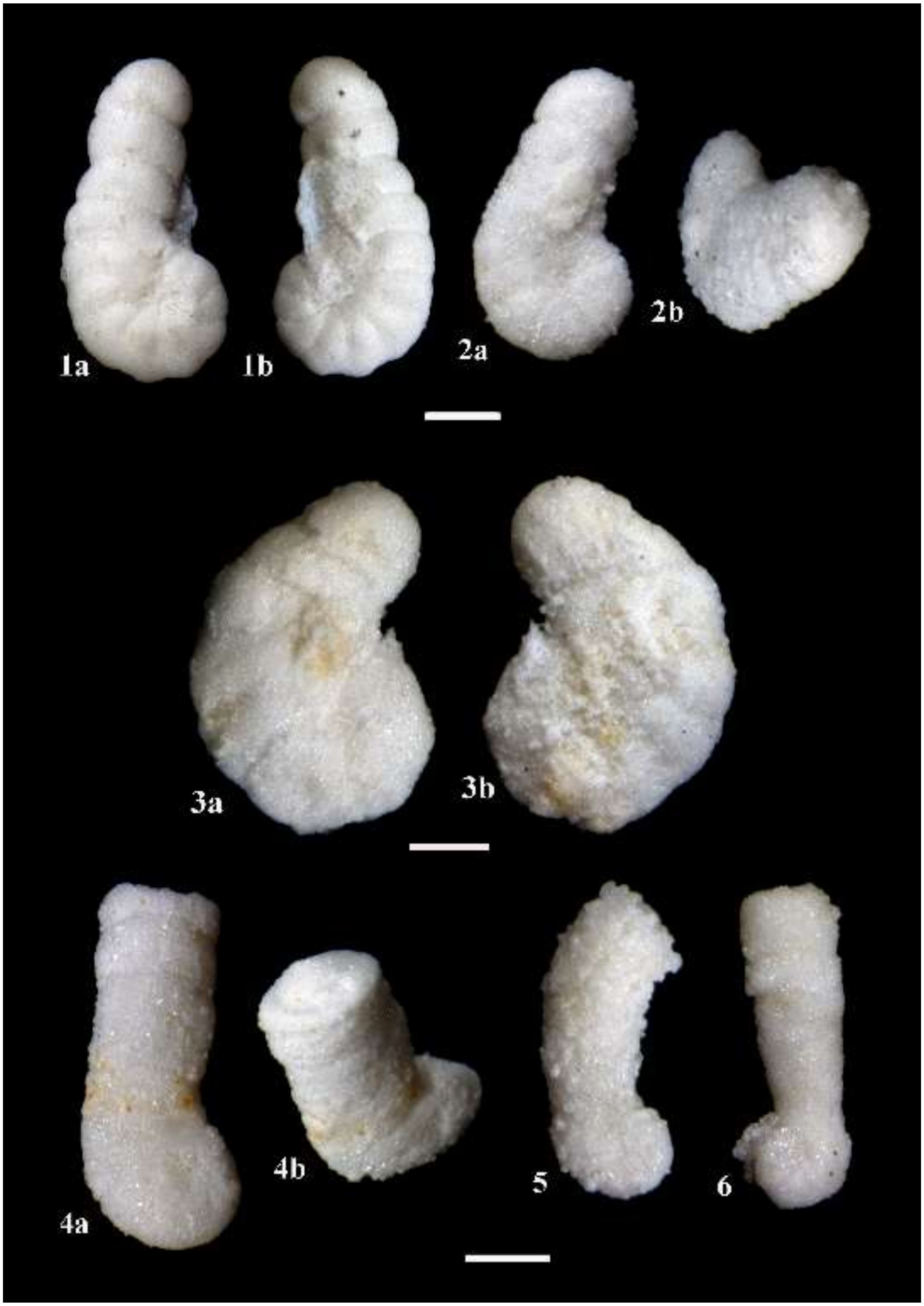
1, 3. *Cibicides* sp. S23/2, S1/11b. **2, 4**. *Rotalia* sp. S1/11a. **5.** *Discorbis* sp. S1/11a. **6, 7**. *Discorbinella* sp. S8/9.

PLATE 6



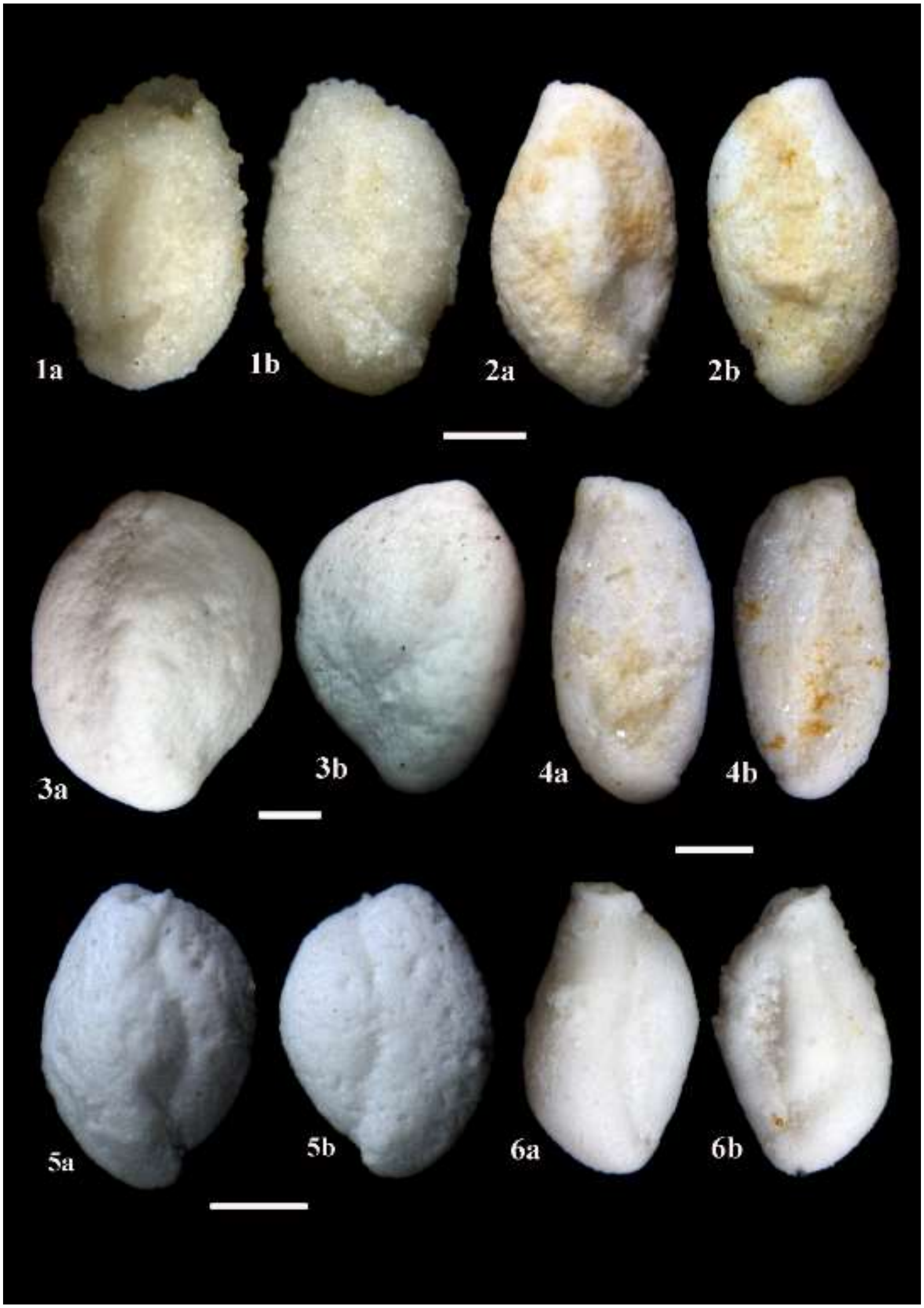
1. *Stilostomella* sp. 1, S8/8. **2.** *Stilostomella* sp. 2, S8/9. **3.** *Stilostomella* sp. 3, S8/9. **4.** *Stilostomella* sp. 4, S23/22. **5.** *Stilostomella* sp. 5, S23/22. **6.** *Stilostomella* sp. 6, S23/4a. **7 – 10.** *Peneroplis* sp. 11, S23/21, S23/21, S23/21, S8/9, S8/9.

PLATE 7



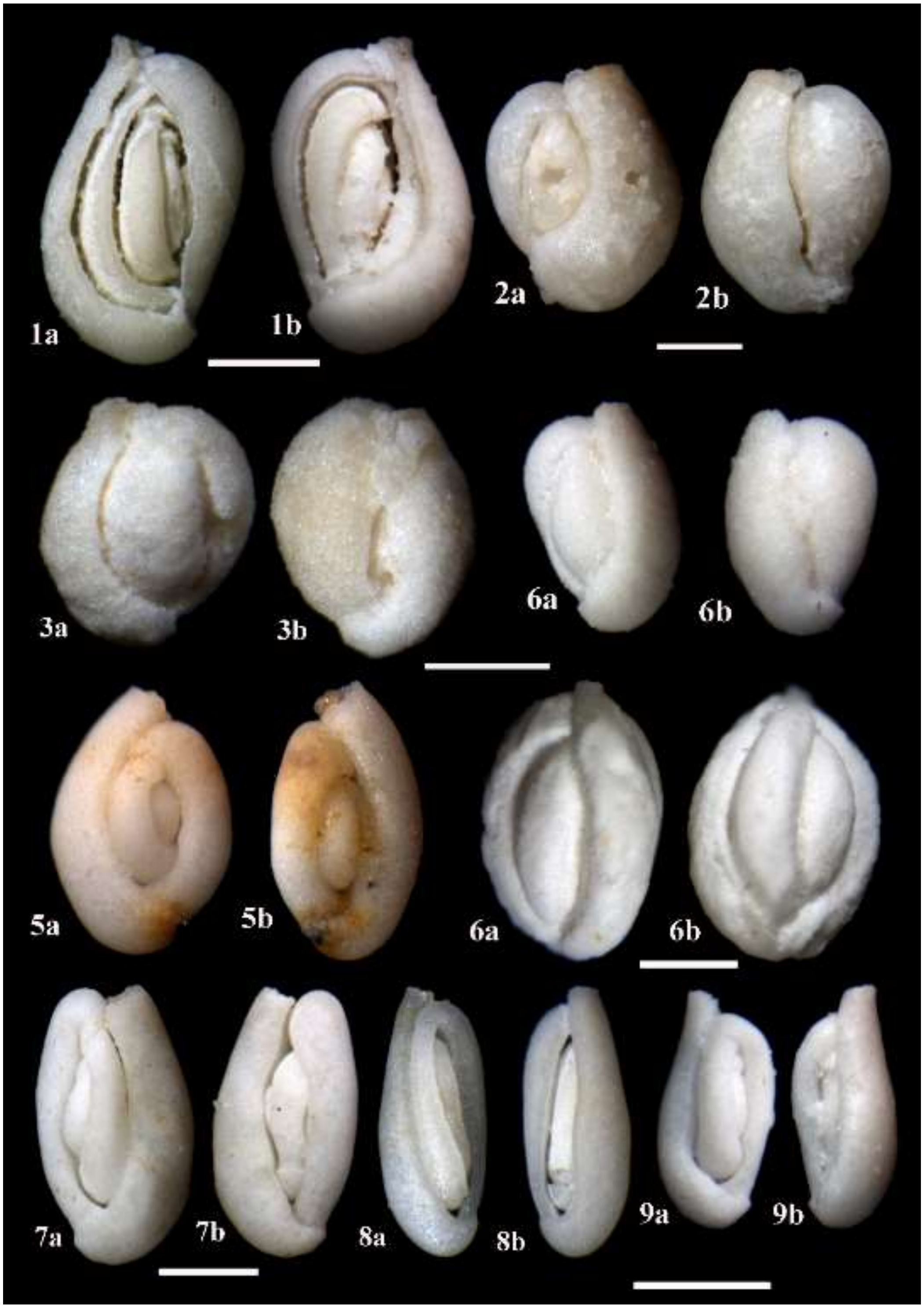
1 – 3. *Coscinospira* sp. (1) S23/4a, (2) S23/21, (3) S2321. **4 – 6.** *Spirolina* sp. (4) S23/21, (5) S8/8, (6) S8/9.

PLATE 8



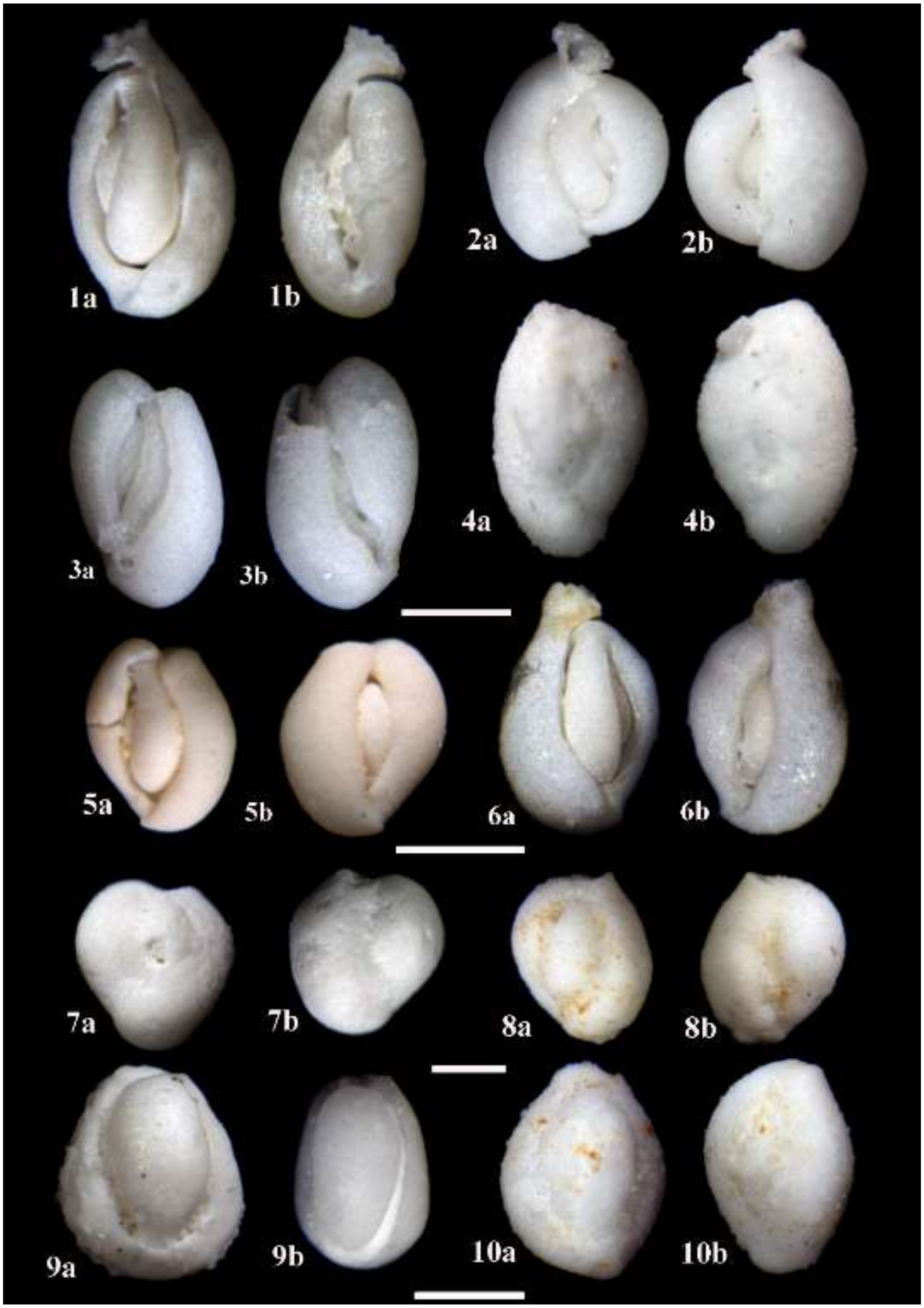
1. *Triloculina* sp. 1, S8/9. **2.** *Triloculina* sp. 2, S23/22. **3.** *Triloculina* sp. 3, S23/4. **4.** *Triloculina* sp. 4, S23/22. **5.** *Triloculina* sp 5, S23/4. **6.** *Quinqueloculina* sp 1, S23/21.

PLATE 9



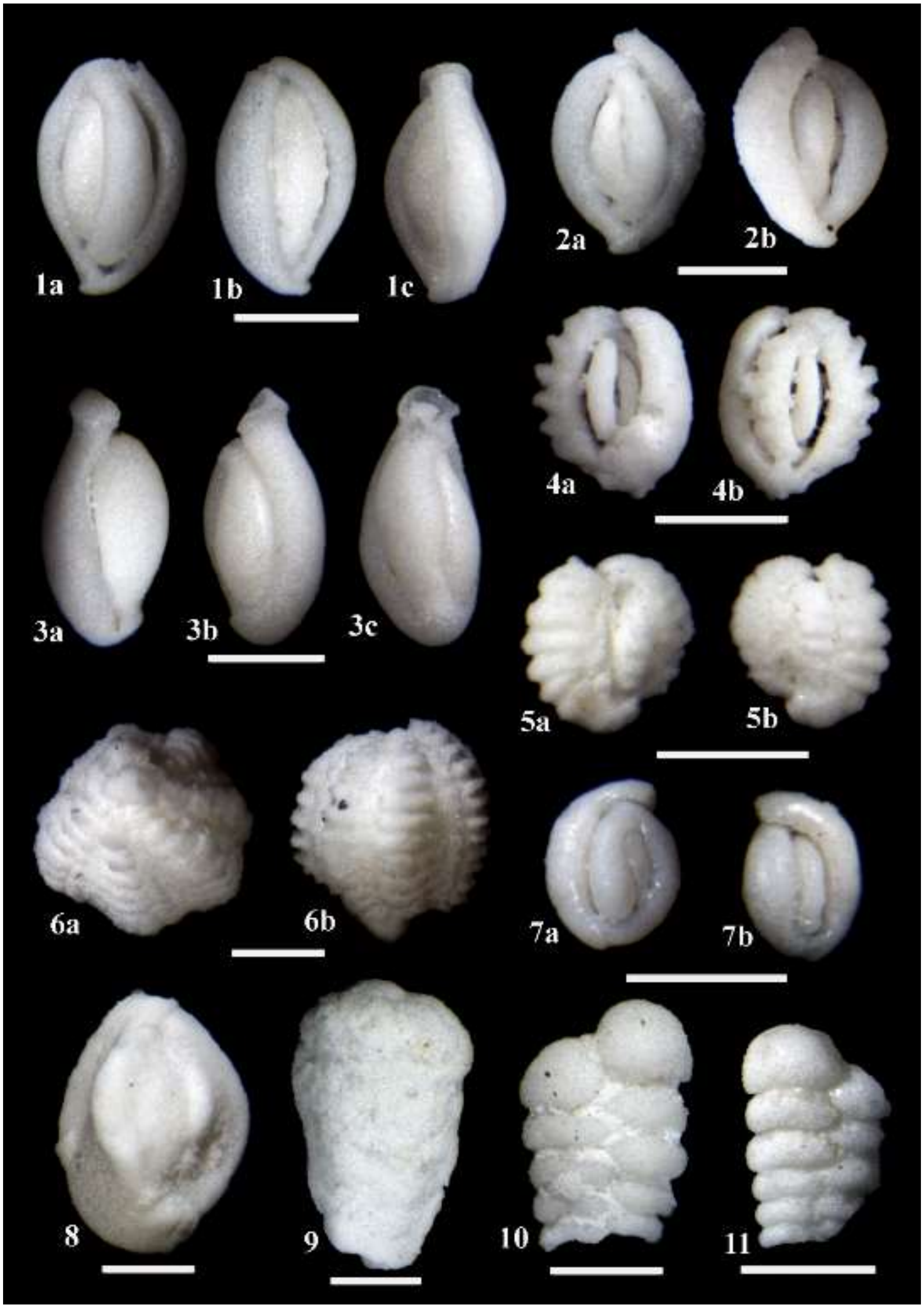
1. *Sigmoilinita* sp. S8/8. **2.** *Triloculina* sp. 6, S8/8. **3.** *Triloculina* sp. 7, S8/8 **4.** *Triloculina* sp 8, S8/8. **5.** *Quinqueloculina* sp. 2, S8/10. **6.** *Quinqueloculina* sp. 3, S23/9b. **7.** *Quinqueloculina* sp. 4, S8/10. **8** a-b *Quinqueloculina* sp. 5, S8/8. **9** a-b *Quinqueloculina* sp 6, S1/9c.

PLATE 10



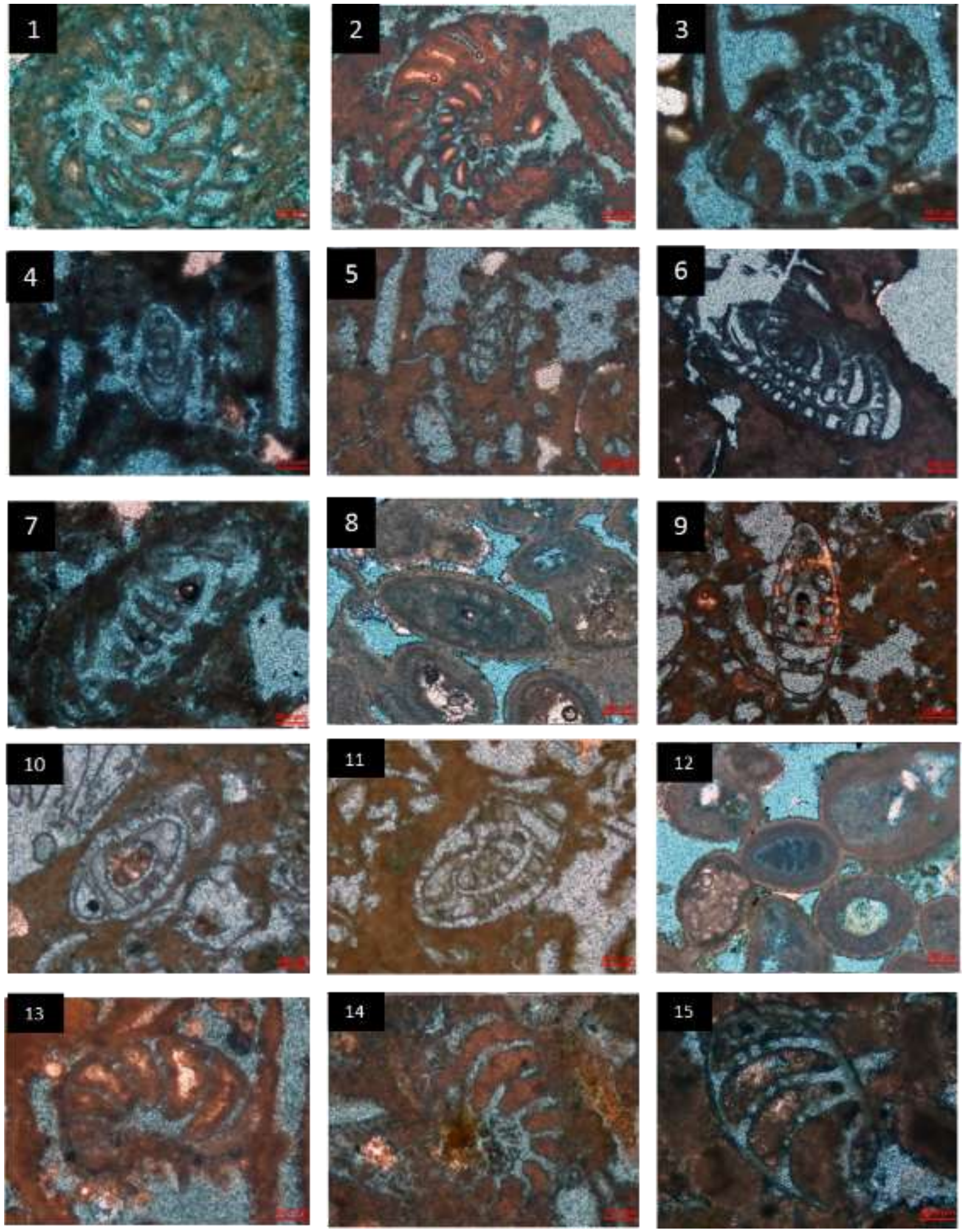
1. *Quinqueloculina* sp. 7, S23/3. **2.** *Quinqueloculina* sp. 8, S1/8. **3.** *Quinqueloculina* sp. 9, S23/3. **4.** *Quinqueloculina* sp. 10, S8/2. **5.** *Quinqueloculina* sp. 11, S8/10. **6.** *Quinqueloculina* sp. 12, S1/6a. **7, 8.** *Pseudotriloculina* sp. S23/4, S23/22. **9a** *Pyrgo* sp. 1, S1/6a. **9b** *Pyrgo* sp 2. S1/8. **10 a-b** *Quinqueloculina* sp 13, S23/22.

PLATE 11



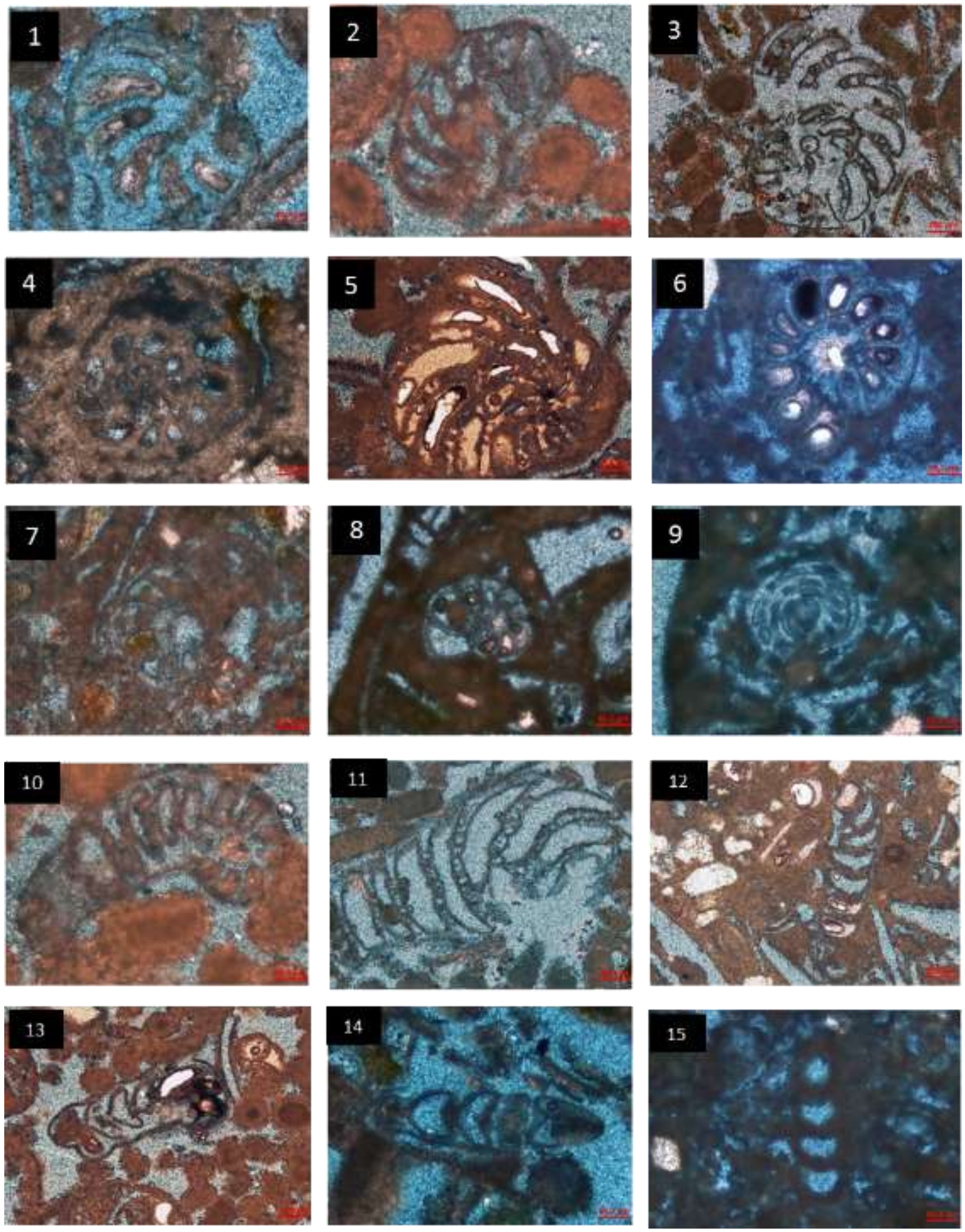
1. *Quinqueloculina* sp. 14, S1/10. **2.** *Quinqueloculina* sp. 15, S1/10. **3.** *Quinqueloculina* sp. 16, S1/10. **4, 5.** *Pseudohaverina* sp. S1/11a. **6.** *Borelis melo melo*, S23/4. **7.** *Quinqueloculina* sp. 17, **S1/10, 8**. *Quinqueloculina* sp. 18, S23/4a. **9, 10, 11** *Textularia* sp. (9) S23/4a, (10) S23/14a, (11) S1/13.

PLATE 12



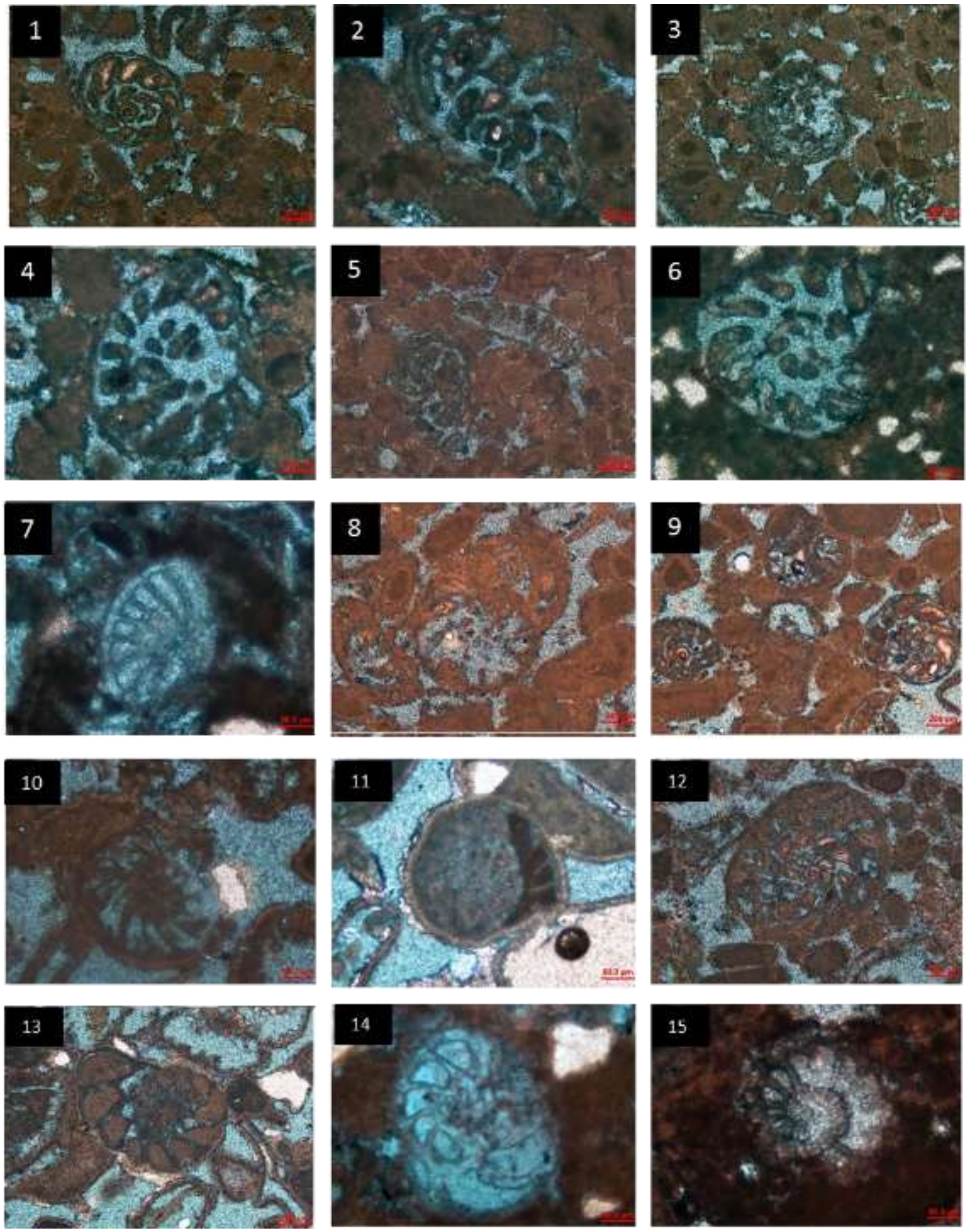
1 – 12 *Elphidium* sp. (1) S8/ 10, (2) S2/8, (3) S23/16, (4) S23/8, (5) S2/11, (6) S23/4a, (7) S23/4a, (8) S23/9a, (9) S23/3, (10) S1/10, (11) S1/10, (12) S23/9a. **13 – 15** *Peneroplis* sp. (13) S2/10, (14) S2/6a, (15) S8/2.

PLATE 13



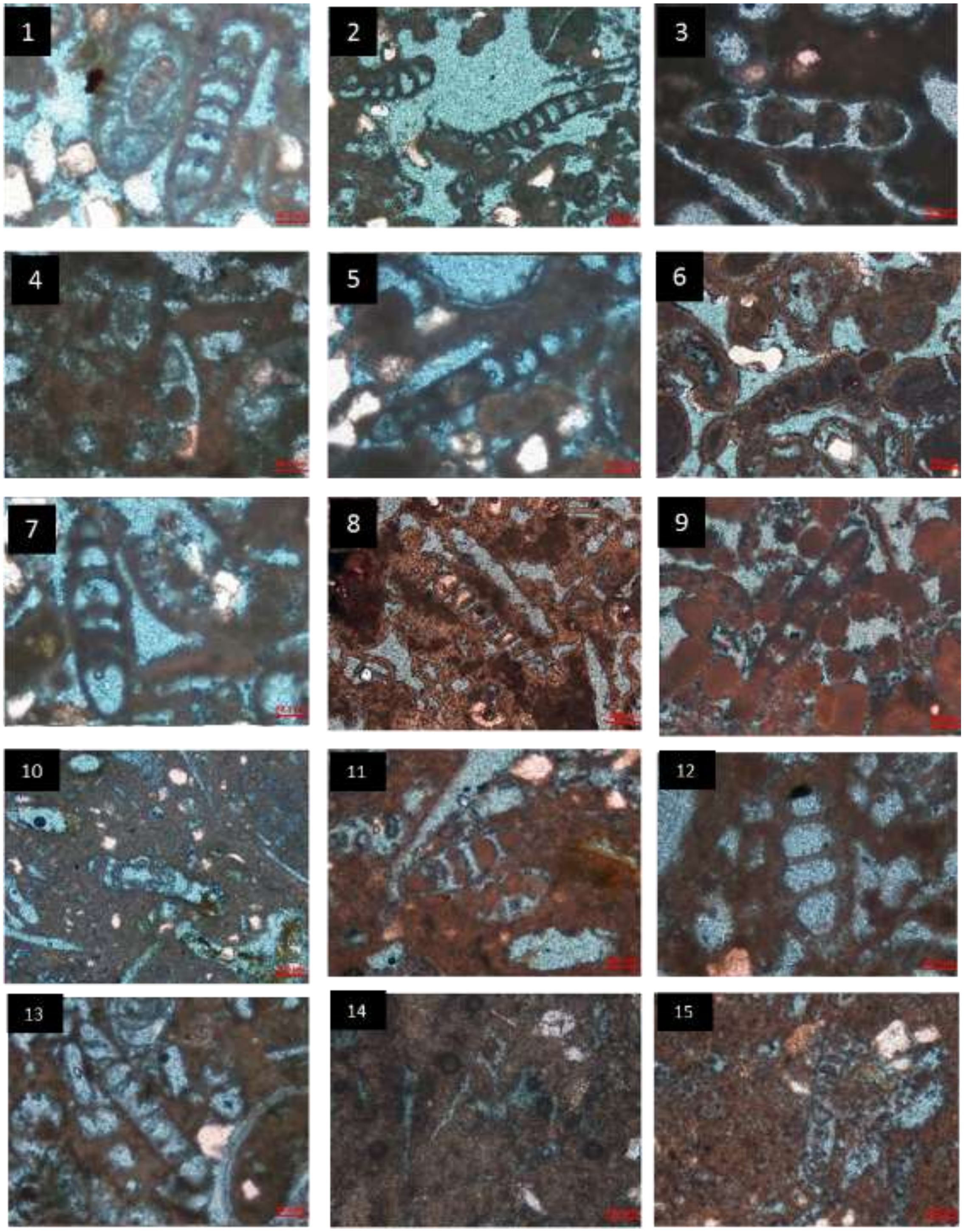
1 – 5 *Peneroplis* sp. (1) S23/1, (2) S2/9, (3) S23/1, (4) S2/2, (5) S2/9. **6 – 8** *Rotalid* sp. (6) S1/10, (7) S1/7, (8) S1/11a. **9** *Borelis melo melo.* S1/11a. **10 – 13** *Coscinospira* sp. (10) S2/9, (11) S23/1, (12) S8/9, (13) S2/9. **14 – 15** *Stilostomella* sp. (14) S23/1, (15) S23/2.

PLATE 14



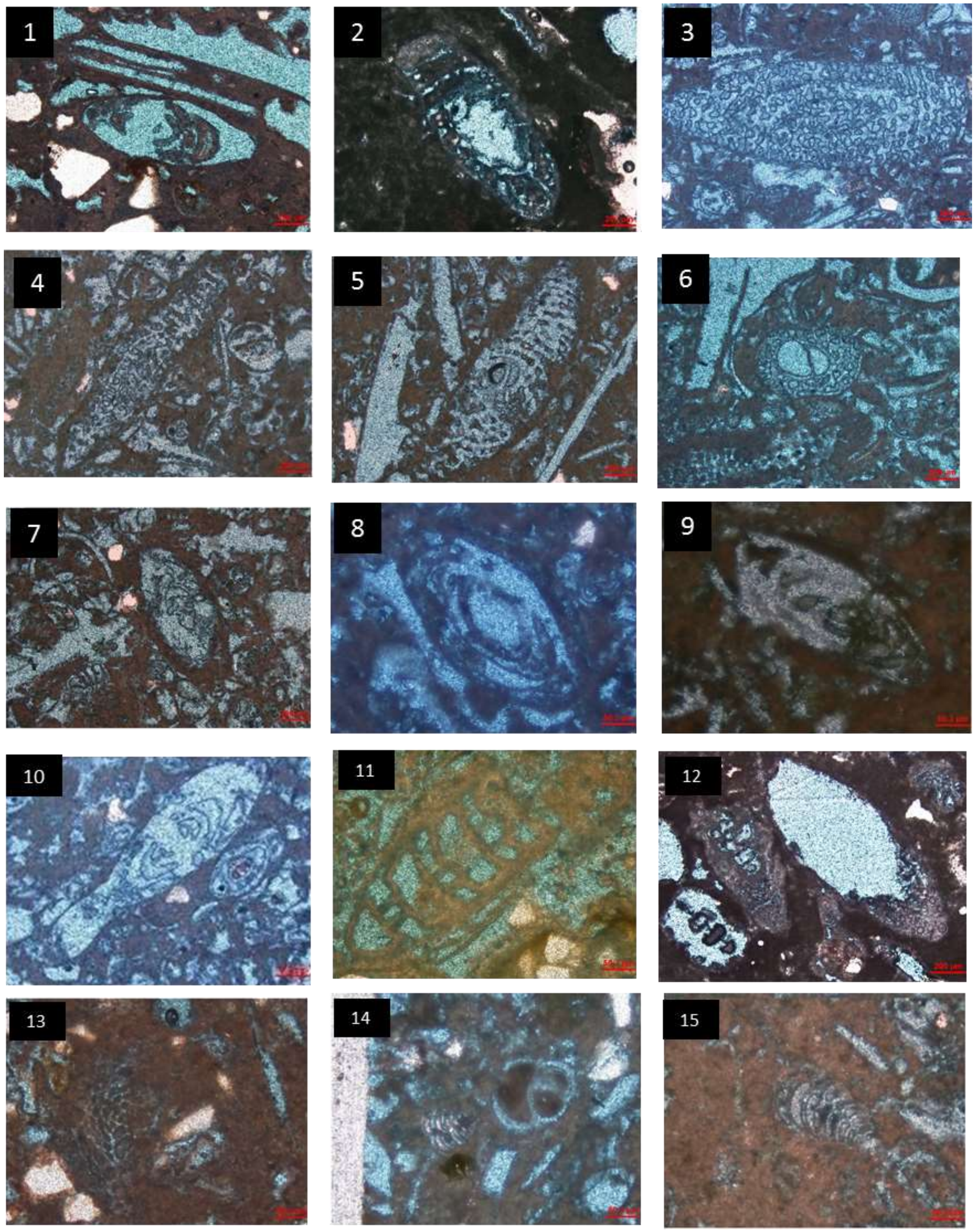
1 – 15 *Ammonia* sp. (1 – 5) S8/2, (6) S8/14, (7) S23/8, (8) S2/10, (9) S2/9, (10) S23/9, (11) S23/9, (12) S23/1, (13) S23/9, (14) S23/8, (15) S23/8.

PLATE 15



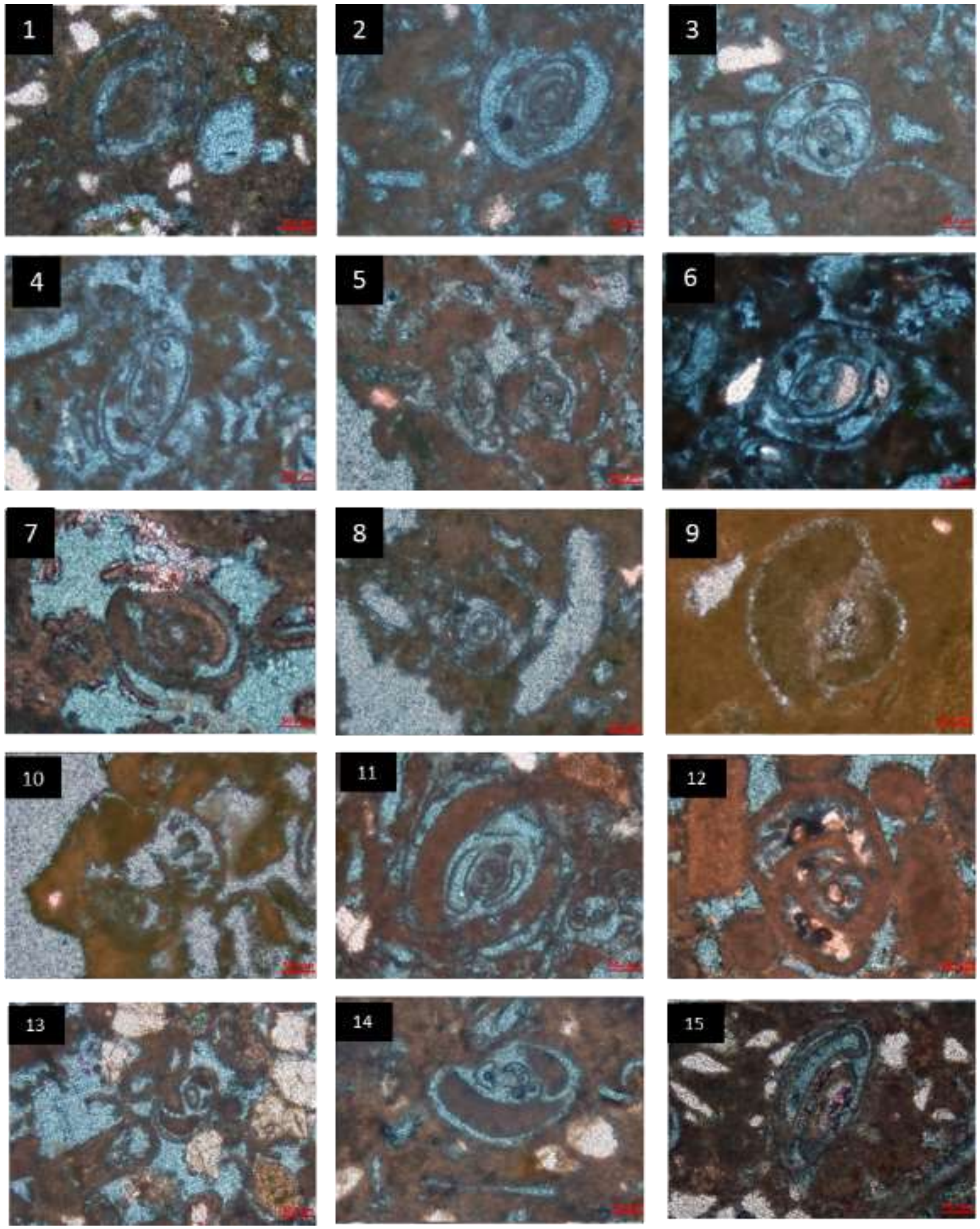
1 – 14 *Stilostomella* sp. (1) S23/21, (2) S23/21, (3) S23/8, (4) S23/8, (5) S23/21, (6) S23/9, (7) S23/21, (8) S2/2, (9) S2/2, (10) S1/6a, (11) S2/6a, (12) S23/8, (13) S1/10, (14) S1/6d. **15** *Cornuspira* sp. S2/6.

PLATE 16



1. *Elphidium* sp. S23/16**.** **2**. *Borelis melo melo*. S23/4a. **3, 4.** Alveolinids. S1/10. **5, 6.** Lepidocyclinids. S1/10. **7, 8, 9.** *Amphistegina*. S1/10, S1/10, S1/11c. **10.** *Operculina* sp. S1/10. **11.** *Elphidium* sp. S8/10. **12.** Gypsinids. S23/4a. **13.** *Planorbulina* sp. S2/6a. **14 – 15.** *Textularia* sp. S1/11c.

PLATE 17



1. *Triloculina* sp. S1/6A **2.** *Quinqueloculina* sp. S1/10. **3 - 5.** *Triloculina* sp. S1/10. **6.** *Quinqueloculina* sp. S1/11a. **7.** *Quinqueloculina* sp. S23/9. **8.** *Triloculina* sp. S1/11c. **9.** *Triloculina* sp. S1/14. **10.** *Pseudohauerina* sp. S1/7. **11 – 14.** *Triloculina* sp. (11) S2/6a, (12) S2/9, (13) S8/9, (14) S8/12. **15.** *Sigmoilinita* sp. S8/4.

Vitae

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Septriandi joined KFUPM as a graduate student at the Geosciences Department (previously Earth Science Department) in 2013. He was working as Mudlogging Engineer at Schlumberger (Geoservices segment) prior to join with KFUPM. He was involved in both exploration and development of offshore shallow water and deep-water drilling operation for 18 months in Indonesia. He current research interest is the Biostratigraphy and Micropaleontology of clastic and carbonate rock. During his time at KFUPM, he spent one month during the summer vacation in 2014 attending the International School on Foraminifera in Urbino - Italy where the Micropaleontologists from around the world from industrial and university backgrounds gathered to study Foraminifera. In summer break 2015, he had the opportunity to visit the AGH University in Kraków, Poland. He spent three months in Micropress Europe at AGH working on identification of Paleogene and Neogene Deepwater Agglutinated Foraminifera from the Angola and Gulf of Mexico offshore wells. During his masters, he published one journal article in internationally recognized ISI journals and four international conference papers. He is also an active member of American Association of Petroleum Geologist (AAPG), European Association of Geoscientist and Engineers (EAGE), and Dhahran Geosciences Society (DGS).

Journal Publications:

1. **Chan, S.A.**, Kaminski, M.A., Babalola, L.O., and Al-Ramadan, K. 2016. Foraminiferal biofacies and depositional environments of the Burdigalian mixed carbonate and siliciclastic Dam Formation, Al-Lidam area, Eastern Province of Saudi Arabia. Paleogeography, Paleoclimatology, Paleoecology. Under Review.

2. **Chan, S.A**, Malik, M.H., Kaminski, M.A., and Babalola, L.O. Optimization of the Acetic Acid method for microfossil extraction from lithified carbonate rocks: Examples from the Middle Jurassic Dhruma Formation and Middle Miocene Dam Formation in Saudi Arabia. Arabian Journal of Geosciences. Under Review.

3. Koeshidayatullah, A., **Chan, S.A.**, Al-Ghamdi, M., Akif, T., and Al-Ramadan, K. 2016. Discrimination of Inland and Coastal Dunes in Eastern Saudi Arabia Desert System: An Approach from Particle Size and Textural Parameter Variations. Journal of African Earth Sciences, v.117, p.102-113.

Conference Presentation:

1. **Chan, S.A.**, Malik, M.H., Kaminski, M.A., and Babalola, L.O. 2016. Optimization of the Acetic Acid method for microfossil extraction from lithified carbonate rocks: Examples from the Jurassic and Miocene of Saudi Arabia, PICO Presentation at EGU General Assembly 2016, Vienna, Austria.

2. **Chan, S.A.**, Kaminski, M.A., Babalola, L.O. 2016. Micropaleontology of Mixed Carbonate and Siliciclastic of Miocene Dam Formation in the Al-Lidam area, Eastern Province of Saudi Arabia. Oral Presentation at GEO 2016 12th Middle East Geosciences Conference and Exhibition, Manama, Bahrain.

3. Kaminski, M.A., Wollenburg, J.E., and **Chan, S.A**. 2015. Pleistocene Agglutinated Foraminifera from Core PS87/030-1-KAL, Lomonosov Ridge, Arctic Ocean. Oral presentation at 16th Czech-Slovak-Polish Paleontological Conference 10th Polish Micropaleontological Workshop, Olomouc, Czech Republic.

4. **Chan, S.A.,** and Kaka, S.I. 2014. A Passive Seismic Experiment and Ground Penetrating Radar to Characterize Subsurface cavities in Eastern Saudi Arabia. Poster presentation at EGU General Assembly 2014, Vienna, Austria.